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This framework was prepared by the State Advisory Committee on Science Education and is designed to provide assistance to persons responsible for science curriculum and instruction, as well as for writers and publishers of instructional materials. It purports to set forth and define the essential ingredients and structure of a K-12 instructional program in science. It spells out a philosophical position and describes the unique nature of science as it relates to science education. Emphasis is placed on a system of curriculum development utilizing goals, operational objectives, instructional strategies, and techniques inherent to any good science program. Prescriptive and definitive listings are avoided. The major divisions are (1) A Philosophical Position, (2) The Nature of Science, (3) A System of Curriculum Development, and (4) Teacher Education. Appended is a listing and discussion of science conceptual themes which can be used in curriculum development. Illustrative lesson materials are described under separate cover. (DS)

Science Framework
for
California Public Schools

PRELIMINARY

U.S. DEPARTMENT OF HEALTH, EDUCATION & WELFARE
OFFICE OF EDUCATION

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CALIFORNIA STATE DEPARTMENT OF EDUCATION
Max Rafferty—Superintendent of Public Instruction
Sacramento 1968

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Science Framework
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California Public Schools

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Prepared for the
California State Board of Education

By the
California State Advisory Committee
on Science Education

A Project Funded Under Provisions of ESEA, Title V,
on authority of the
California State Board of Education

PREFACE

The Science Framework for California Public Schools was prepared by the State Advisory Committee on Science Education at the direction of the California State Board of Education. It purports to set forth and define the essential ingredients and structure of an appropriate instructional program in science for kindergarten through grade twelve.

Recognizing that behind any such document there must be a rationale, the Committee carefully spelled out its philosophical position and described the unique nature of science as it relates to science education. Emphasis is placed on a system of curriculum development utilizing goals, operational objectives, instructional strategies, and techniques inherent in any good science program. Prescriptive and definitive listings are avoided. While all listings are illustrative and open-ended, they are useful in designing a "model" for assistance to persons responsible for science curriculum and instruction, as well as writers and publishers of instructional materials.

Without well-prepared teachers the best of materials can produce little. Accordingly, special attention is given to teacher preparation.

EUGENE GONZALES
Associate Superintendent of
Public Instruction; and
Chief, Division of Instruction

MITCHELL L. VOYDAT
Chief, Bureau of
Elementary and
Secondary Education

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Former Members of the State Advisory Committee on Science Education (locations at time of service):

Frank B. Lindsay (Chairman), Bureau of Elementary and Secondary Education, State Department of Education

Hiden T. Cox (Chairman), California State College, Long Beach

Thomas E. Beall, Jr., San Bernardino City Unified School District

Ray D. Owen, California Institute of Technology, Pasadena

Donald M. West, San Jose State College

Members of the Curriculum Commission Committee on Science:

Hiden T. Cox, California State College, Long Beach

Laura H. Doyle, Menlo-Atherton High School, Atherton

Ruth Howard, Lowell High School, San Francisco

H. M. McPherson, Retired, Napa City Schools

D. Russell Parks, Fullerton Elementary School District

Special Consultants and Writers (locations at time of service):

Wallace R. Brode, American Chemical Society, Washington, D. C.

Jacob Bronowski, Salk Institute of Biological Studies, San Diego

Bruce Carpenter, California State College, Long Beach

Robert M. Gagne, University of California, Berkeley

Peter Gega, San Diego State College

Robert F. Mager, American Institute of Research, Palo Alto

Frederick J. McDonald, Stanford University

Mario Menisini, Orinda Union Elementary School District

Douglas L. Minnis, University of California, Davis

Ester Nelson, Bureau of Elementary and Secondary Education, State Department of Education

Charles Roberts, California State College, Long Beach

W. Earl Sams, Bureau of Elementary and Secondary Education, State Department of Education

J. Rae Schwenck, Bureau of Elementary and Secondary Education, State Department of Education

Celia Stendler, University of California, Berkeley

Frank Swatek, California State College, Long Beach

Editor:

Sister Agnes Schmit, San Diego College for Women

STATE ADVISORY COMMITTEE ON SCIENCE EDUCATION

Chairman (Acting):

Richard A. Smith, Professor of Physical Science and Science Education, San Jose State College

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Graydon D. Bell, Professor of Physics, Harvey Mudd College, Claremont

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Adrian N. Gentry, Director of Curriculum, Office of the Riverside County Superintendent of Schools

Ralph W. Gerard, Dean of the Graduate Division, University of California, Irvine

Serafino L. Guiliani, Curriculum Service Division, San Diego City Unified School District

John Hofstetter, Vice Principal, San Andreas Elementary School

Paul DeHart Hurd, Professor of Education, School of Education, Stanford University,

Henry Rapoport, Professor of Chemistry, University of California, Berkeley

John L. Ryan, Science Teacher, Hancock Elementary School, San Francisco

Edward Shevick, Science Instructor, Gaspar de Portola Junior High School, Tarzana

Lee B. Stephens, Jr., Associate Professor of Biology, California State College, Long Beach

Harry K. Wong, Biology Teacher, Menlo-Atherton High School, Atherton

Coordinator:

L. Frank Mann, Consultant in Secondary Education, Bureau of Elementary and Secondary Education, State Department of Education, Sacramento

CONTENTS

Page

PREFACE iii

ACKNOWLEDGMENTS v

STATE ADVISORY COMMITTEE ON SCIENCE EDUCATION vii

Chapter

I. Philosophical Position 1

II. Nature of Science 7

III. A System of Curriculum Development 13

- A. Description of the System 14
- B. Using the Framework 14
  - 1. Goals 15
  - 2. Operational Objectives 23
  - 3. Components of Instructional Strategy 31
    - a. Selection and Sequence of Content
    - b. Selection of Instructional Media
    - c. Learning Theory Related to the Goals
    - d. Diagnosis and Evaluation
    - e. Techniques
- C. Seeking A Consistent Model of Science Instruction 42
  - 1. What We Mean by Consistency 42
    - a. In Strategy
    - b. In Technique
  - 2. Criteria for Evaluation of Illustrative Materials 45

IV. Teacher Education 47

- A. Need for New Design in Training Programs 48

CONTENTS

Page

B. Preservice Education 50

C. Continuing Education 57

V. Recommendations 67

VI. Bibliography 69

VII. Glossary 71

Appendix 75

A. Conceptual Themes 75

CHAPTER I

THE PHILOSOPHICAL POSITION

Science - A Part of American Culture

The interplay between science, technology, and social change has led America into a new era in history: AN AGE OF SCIENCE. It becomes increasingly clear that the knowledge generated by science through its investigative procedures is a major force in shaping the modern world. People who fail to develop an appreciation of the scientific enterprise and its influence upon America's social and economic structure are quite likely to become foreigners within their own culture. Science has become broadly integrated into the whole of life, its intellectual as well as its humane phases. The achievements of science have great potential for improving the welfare of mankind, both social and aesthetic. Within this context, therefore, an education in the sciences becomes essential for all. One purpose of science education must be the development of citizens who have an understanding of science, its processes, and its achievements.

Science - A Process of Rational Thinking

While modern science has contributed much to our material resources, its greatest contribution, perhaps, has been the extension of man's intellectual achievements, resulting in a better understanding of nature and nature's laws. But we expect young people, through a study of science, to acquire something more than an understanding of natural events; we want them to have confidence in rational thinking. Science is a pattern of concepts and principles resulting from observation and experimentation. Therefore, the teaching of science should form habits of rational thinking while at the same time developing an understanding of natural phenomena.

Science - A Basic Component of Liberal Education

Science in the twentieth century is a basic component of liberal education. As we examine more closely the essential place of science in a liberal education, we see that there are three elements involved, which require: 1) a definition of liberal education, 2) evidence that such an education is desirable, and 3) a definition of science.

We may consider a liberal education as one which befits a man of free birth, which is not servile or restricted, nor bound by orthodox tenets, but which allows for independence of thought and judgment. The desirability of such an education may be seen from its objectives, which apply to everyone and which are a necessary foundation in man's endeavor to understand himself and his heritage. These objectives are: 1) to provide knowledge--knowledge of man and his accomplishments, and knowledge of the universe, 2) to teach communication skills, such as language, mathematics, and the skill of thinking, 3) to develop attitudes of intellectual objectivity, curiosity, of questioning, and of readiness to accept or create new ideas.

Science, in its turn, has been variously defined. Basically, we can define it as the interpretation of experiences and observations by logical, systematic generalizations which must stand the test of quantitative experimentation. However, to be truly liberal, a high quality science program can be achieved only when it is developed within a system of education where the term "science" has an even loftier meaning. Warren Weaver understood this when he wrote:

> "Science is an adventure of the human spirit. It is an essentially artistic enterprise, stimulated largely by curiosity, served largely by disciplined imagination, and based largely on faith in the reasonableness, order, and beauty of the universe of which man is a part."
>
> . . . Warren Weaver: "A Great Age for Science"[1]

These definitions of liberal education and of science indicate that science is uniquely suited to meet the objectives of liberal education. 1) Science provides a catalogue of knowledge about the world of living things and the physical universe in which man exists. 2) Science develops the skills of logical thought by the exercise of critical observation, controlled experimentation, and rational generalization, while using the fundamental tools of precise language and mathematics. 3) Science develops a critical questioning attitude in which experimental justification, not authority or absolutes, is definitive. 4) Science acts as a force producing change and new ideas. 5) Science proceeds by rational inquiry, as man searches for a deeper understanding of truth.

The Science Curriculum

1. Its Function

The science curriculum exists to help our young people understand and participate in the life of our rapidly emerging, science-dependent society. New science curricula have resulted from the influences of this changing, highly specialized society which demands well educated scientists trained in technological skills. But growing institutionalization and complex interrelationships of society call also for highly educated non-scientists who are scientifically literate and who understand the processes of science.

2. Its Integrated Sequence

There was a time when we thought of a science curriculum as simply an arrangement of science information by grade levels. The conceptual organization of the science disciplines was seldom considered, and little attention was given to the logical processes that make "science" really science. However, we have come to recognize that an education in the sciences becomes truly such only in the context of the enterprise of science, and that science teaching becomes liberal education only within a social and humane context. Even more significantly, the science curriculum, in its turn, favors such an education only to the extent to which the spirit of science is integrated into instructional practices. Too often the major learning demands on pupils in science courses have been to acquire, often by rote, a number of facts about science topics. Some of the findings of science, even when not disproven by later ones, often become trivial by virtue of richer insights or wider generalizations. Others, which can be proven and endure, make it tempting to teach science by dogmatic assertions of truth. This is comparable to being told the answer to a puzzle or the score of a game rather than learning the rules and strategy and then living through the actual play, as an active participant.

---

[1] Warren Weaver, "Goals for Americans: Chapter IV," in A Great Age for Americans. New York: Prentice-Hall, Inc., 1960, p. 105.

3. Its Fertility

A good learning experience in science should be a minimally structured voyage of discovery, with new observations provoking new thoughts which generate new observations. The student should be captain, with certain guiding beacons provided by the teacher. The formal guides of student texts and laboratory manuals, and of teachers' supplements, should serve only as aids to the limited resources of teacher and materials. These aids, necessarily formal and rigid, can put reality into a straight jacket. They must be relegated to a minimal role so that the student and teacher can attend to the fluid process rather than the fixed outcome. Learning "concepts" or "strands" is better than memorizing facts. Acquiring interests, skills, and habits--of eye, hand, and mind--is better than either. Books and films are but learning aids, and only supplement the potentially best learning aid of all--a responsive teacher who is able to encourage and lightly guide the uncertain student.

Summary Statement of Position

The California State Advisory Committee on Science Education recognizes that, as science and society change, the science curriculum in schools needs to be re-evaluated and made consistent with newer developments. We also recognize that from time to time the goals of science instruction, as well as the content and organization of the science curriculum, must be brought into review and the balance corrected between the demands of the modern age and the state of the curriculum. The Committee has given serious consideration to guidelines that may be used by elementary and secondary school teachers to focus debate upon curriculum improvements in science. Deliberations within the Committee have led us to take the following positions on science teaching, which we believe are consistent with the nature and spirit of science, the educational demands for living in our scientific-technological-industrialized society, and consistent with the humanistic demands of this age. We believe that:

1. A knowledge of the scientific enterprise is central for an appreciation of contemporary civilization, not alone for its intellectual achievements but also as a factor in understanding modern social, economic, and political developments.

2. A major goal of education is the development of the powers of rational thinking and that the proper study of science must therefore stress the logical processes and experimental methods of scientific inquiry.

3. Knowledge of basic concepts and general laws are essential to understanding science and that the teaching of bare facts does not serve this end.

4. Individuals should be sufficiently literate in science to appreciate its spirit of inquiry and its basic concepts, and how to use both for the advancement of human welfare.

5. The student should understand the relationship between science and technology and appreciate the contributions that both have made to the intellectual and economic development of America.

6. The curriculum in science at all levels should be organized around representative conceptual themes, their major supporting concepts, and around the processes of science, since concepts and inquiry processes are a more economical and a more highly transferable form of learning.

7. The sequence of instructional materials from kindergarten through high school should be organized around:

    a. the major conceptual themes of science, to provide vertical coherence to the curriculum. Supporting concepts should be introduced at several grade levels to increase the comprehensiveness and the interpretive power of each concept.

    b. the logical processes of science with a continuing refinement in meaning at each level of presentation.

8. A wide range of instructional media--reference books, films, laboratory and field experiences, among others--is essential for learning science in a scientific way and for motivating pupils.

9. The evaluation of pupil or student achievement should be made with respect to:

    a. his ability to think rationally about problems involving a knowledge of science.

    b. his ability to interpret the natural world.

    c. his understanding of the nature of science.

10. Elementary and secondary school teachers should be encouraged and supported in developing, using, testing and evaluating:

    a. new experimental curricula

    b. new instructional media

    c. new ways of learning

    d. innovative practices that may lead to the improvement of science teaching in California schools.

    A continuing program of research and development, and the testing of research findings in the classroom, are not only desirable activities for teachers and administrators but are essential for educational advancement.

The Committee is of the opinion that these recommendations are consistent with each other and provide a logical and coherent philosophy for an education in the sciences in California schools.

CHAPTER II

THE NATURE OF SCIENCE

Science - A Remarkable Discovery

The most remarkable discovery made by scientists is science itself; that is, scientists owe their growing success during the last 300 years to the way in which they have been able to turn science into a method. And the strength of the method is that it can be taught and learned; more people have learned to be scientists in our lifetime than in all human history before us. We cannot teach people how to make great discoveries, of course, but we can certainly teach them how discoveries are made. The evolution in the last 300 years of this method has been the essential discovery of science.

Science - A Method of Discovery

In this sense, science is a method of discovery. There are evidently two things to be asked about such a method: how it works, and why it works. Neither of these questions is simply technical; on the contrary, their answers imply a special relation and attitude of man to his environment, and that is why they are important to every thinking person.

Science - An Organization of Knowledge

How does the scientific method of discovery work? To answer, we must be clear in our minds that science is not a mere register of facts--and indeed, that our minds are not made (like a cash register) to tabulate a series of facts in a neutral sequence one after another. Our minds connect one fact with another, they seek for order and relationship, and in this way they arrange the facts so that they are seen to be linked by inner laws in a coherent network. Science is an organization of knowledge.

The facts are there for us to observe, but their organization is not; it has to be discovered step by step, and each step has to be probed and tested. The nub of the scientific method is the procedure of testing whether the model of the inner organization of nature that we have formed remains consistent with the facts when we add a new fact to those from which we began. From the known facts we form a model of how we think nature is organized--that is, of her laws; and now we ask whether the model really works as nature does, not only in those places where we already know the facts, but in a place where we do not.

The Crucial Test

This is the crucial test, and to make it we must constantly think of places that have not yet been explored. Therefore, we seek the implications of our present model, and ask it to predict how nature will behave in a new and wholly different situation. The prediction is made by reasoning logically from the model, but it can only be tested by confronting nature with the new situation. Sometimes such a situation occurs of itself, and we have only to wait for the opportunity; so astronomers had only to wait for the eclipse of 1919, and good weather, in order to test Albert Einstein's prediction that light is bent towards massive bodies. More often we have to create such a situation artificially, as Gregor Mendel did in his monastery garden to test his theory of inheritance, or as modern geneticists have done to test Watson and Crick's model of the DNA helix. In essence, every good experiment is a challenge of this kind to nature, which requires her to declare herself for or against our model of her. The laboratory is a convenient setting for the challenge, simply because it is designed to keep out whatever is irrelevant to it. There we try to strip the test to its naked essentials.

The Basic Nature of Discovery

If nature responds to the challenge of our experiment with a fact which contradicts our prediction, then our model of her organization was wrong. That is simple and precise, as J. J. Thomson's discovery of the electron was. But when nature conforms to our prediction, the matter is not so simple. Our model now has a new fact to support it, but support is not proof. The new fact is just another fact to be added to those we already have; it confirms the application of the model, and widens its range, but it cannot be decisive--it cannot show that the model is universal. Evidently no model is universal, and the point of our experiments is inevitably to uncover a situation sooner or later in which the model fails. It is not an accident that the scientific theories of a hundred years ago look crude and primitive today, and mistaken in many of their underlying concepts. It is the fate of theories to be right up to a point, and thereafter wrong; and this precisely is the basic nature of discovery.

The Progress of Science

Thus the progress of science relies on a constant to and fro between two procedures. On the one hand, there is the procedure of reasoning to find new implications of the model of nature that we have formed. And on the other hand, there is the procedure of setting up practical experiments to test these implications in new situations which are as decisive as we can make them. Sooner or later, a decisive experiment reveals that our model of nature is mistaken in some respect--or (to put the matter in a more succinct way) is deficient, because it fails to include among the facts that it explains the new fact which we have tested. Thereupon we have to amend our conceptual model so that it becomes large enough to include the new fact. And so we begin a fresh round of reasoning to find the implications of the new model, and then of testing these implications empirically in experiments which present nature with new situations.

The Middle Ages (leaning upon the axiomatic approach of the Greeks, and particularly of Aristotle) thought that knowledge of nature could be gained by one of these procedures alone; namely, reasoning from a basic model, whose features they believed were self-evident. Francis Bacon, early in the 17th century, turned this view upside down, and proposed that practical observation and experiment alone would yield a knowledge of nature. He believed that the laws of nature, and a connected model of their organization, would, of themselves, flow from this empirical knowledge, and leap to the mind in a self-evident way. But from the day in 1666 when Sir Isaac Newton conceived the law of gravitation, and at once thought out a test for it by calculating the period of the moon, science has worked by coupling the two procedures in alternate steps: reasoning from a model to new implications of it, and then testing the implications empirically by practical experiment and observation. This coupling of reason and empiricism, in a constant "leapfrog one over the other," was explicitly enunciated by Alfred North Whitehead fifty years ago.

In the years that have passed since then, it has become clear that there is a third agent in the progressive march of science. Karl Popper and J. Bronowski have demonstrated that when an empirical test shows that our model is deficient, it is not self-evident in which of several possible ways the model is best changed; and the next model cannot be constructed by any logical process of pure reasoning. The new model, with its new concepts and relations, can only be conceived by an act of imagination. What Francis Bacon called induction is really imagination; and the progress of science from model to test, and from test to new model, requires the human imagination as a third active agent.

So the progress of science is not a mechanical march. It has to be guided and fired at critical moments by highly original (and in that sense, personal) acts of conceptual imagination. The change from Newton's system of the world to a new outlook hung fire from the 1880's until 1905, because a new and fundamental conception had to be invented, and the great minds of men such as H. A. Lorentz and Henri Poincaré were busy trying to make that radical innovation. In the end, it needed the outstanding imagination of Albert Einstein to form this conception fully, in the principle of relativity, as a profoundly new way of visualizing the organization of events--at bottom, as a new philosophy of nature.

How Science Works As A Method

Hence we find that the answer to the question, "How does science work as a method?" is by no means a mere technical specification. It combines abstract reason and practical experiments, and with them crucial moments of imagination when a decisive experiment has faced reason with an impasse. At such moments there is created not merely a new model of nature, but a new conception of her which amounts to a new philosophy. We must not overlook the fact that for three centuries now the most important and radical changes in philosophy (including our view of man and of society) have come from science.

The scientific method, seen in this way, is directed to enlarging our understanding of nature by making new discoveries. There is an underlying assumption here that nature can be understood rationally by the human mind, but also that this understanding is never complete. Each of our models falls short of nature's totality, so that new discoveries always remain to be made, and the potential of nature is always greater than our knowledge. The philosophical premise that nature can be rationally understood has been familiar roughly since the time of Charles Darwin, a hundred years ago. But the other philosophic premise has only recently become clear, namely, that there constantly remains in nature a potential that we have not yet discovered.

We can, therefore, summarize the HOW of the scientific method in a single definition:

> Science is the organization of our knowledge in such a way that it commands more of the hidden potential in nature.

The first part of the definition summarizes in the word organization the three-legged conjunction of reason, experiment, and imagination. The second part of the definition states our belief that we progress by constantly uncovering more in nature than we knew to be there.

WHY Science Works As A Method

This definition faces us sharply with the second question, which we have silently avoided until now: "WHY does science work as a method?" Why has science been successful for three hundred years in steadily enlarging man's control over his physical and biological environment? Why have we achieved a command of natural forces which is so much more effective and persuasive than our command, say, of social forces?

The answers to these questions are implicit in our definition, namely, that it is knowledge of nature that gives us command of her potential. This is the essential conception on which science rests, and it is a relatively modern conception. It was unknown in the Middle Ages. At that time many men still thought that the forces of nature could be dominated by magic. The alchemists of those ages were not seeking the laws of nature, but, on the contrary, their own selfish ends, which would turn the laws aside. Their underlying belief was that man could turn nature to use by bewitching her so that she would be compelled to run counter to her normal laws.

The essential discovery which we call science is an outright rejection of this view. Science believes that the potential of nature cannot be commanded by magic, or by exhortation, or by persuasion; it can be commanded only by knowledge. We cannot overthrow the laws of nature, nor even flout them; that is not the way to bend nature to the human will. Instead, what we have to do is to discover the laws and organization of nature, and then think of ways in which we can use them to do for us what we want done. That is how the dynamo was invented, as well as the radio waves, x-rays, antibiotics, the jet engine, and the laser beam. Science works in practice exactly because it works in theory--because it accepts the inner organization of nature as it finds it, and then arranges to put it to human use. No magic spell could have produced a nuclear chain reaction; it was produced from the modest finding that natural uranium contains several isotopes, and then by patiently sorting out one isotope from another--nothing more. There can be no more vivid demonstration of the definition. We command the hidden potential in nature by the organization of our knowledge.

A Basic Change of Outlook: Its Effect Upon Society

Thus the success of science has its roots in a basic change of outlook which began over four hundred years ago. It was then that Renaissance thinkers came to take a different view of nature, and to see her not as an antagonist but an ally. The key to a fuller physical life, they saw, is not a secret hermetic formula--the philosopher's stone, or the elixir of life--that will cow nature and force her to run counter to her own laws. On the contrary, the key is knowledge: an active and practical method of discovery which enters into the very processes of nature, and thereby learns to direct them to human ends. For example, the alchemists tried for centuries to conjure one metal into another, and failed; yet we now know how to do it, simply because we have learned how nature does it in the stars.

So profound a change in outlook is not merely a technical matter, or a useful device for professionals. The scientific temper has spread through the whole community of man, and created a universal climate in which knowledge is indeed seen as the key to a full life--a consistent intellectual life as well as a full physical life. For example, the gradual erosion of superstition by science is, we now see, something more than a happy accident; it lies at the root of our conviction that nature can be rationally understood, and can be guided to our ends by understanding. One of the major social influences of science has been the belief, in this sense, in the power of knowledge. This is basic to the democratic view that every man has the right to be heard and have a voice in guiding the actions of his community. Precisely here has the experience of science shown the value of the dissident voice. This has been a powerful social influence in smoothing the way for the evolution of western society by democratic reforms.

There is another feature of modern, and particularly western societies, which is bound up with the scientific method. Science is an active mode of knowledge; it does not believe, as some oriental cultures do, that the universe can be plumbed and understood by contemplation alone. Reason and imagination are indeed necessary to the progress of knowledge, but they have to be tested constantly by active experiments. Moreover, the scientific method does not claim that human findings will ever be final. On the contrary, it is a method which proceeds to enlarge knowledge by a constant series of corrections and refinements. A passage from W. K. Clifford puts this cogently:

> "Scientific thought is the guide of action; the truth at which it arrives is not that which we can ideally contemplate without error, but that which we may act upon without fear."[2]

Clifford drew from this statement the bold conclusion that

> "Scientific thought is not an accompaniment or condition of human progress, but human progress itself."[3]

2/W. K. Clifford. The Common Sense of the Exact Sciences. Edited by Alfred A. Knopf, Inc., 1946

3/ibid

No doubt this overstates the place of science in our society. Yet it does draw attention to the essentially active outlook which science has given to the modern world, the reliance on originality and individuality, the hard-working drive for personal achievement as the foundation for communal progress. To us the meaning of human life is its achievement--particularly the achievement of knowledge.

The ETHIC of Science: Adherence to Truth

It is sometimes asked whether science has any ethical meaning: "Surely," say the doubters, "knowledge is neutral?" And, indeed, knowledge as a closed and ticketed entry in a catalogue of facts is neutral, because in that form it is as lifeless as any other museum exhibit. But the pursuit of knowledge, the dedicated struggle from the known to the unknown, the will to extend the territory of truth, that is not neutral. It demands from the community of scientists the highest standards of cooperation and trust, and these in turn can only hold if every member of that community accepts the demand for complete honesty and integrity in his own work.

Scientific knowledge is achieved step by step by men who put the truth before everything else. Imagination in science is only a servant of truth, and reason is only an agent of truth. For the ultimate judge and arbiter is the experimental fact. The facts must be literally and precisely true, without evasion or manipulation. No appeal to dogma or to expediency can relieve the scientist from the duty to abide by that single-minded ethic.

Of all the social consequences of science, the spread of the ethic of truth is probably the most far-reaching. In this century, it has effected marked changes in private belief and in public conduct, and has been a powerful force in fostering the growth of a self-reliant democracy. It has been the chief agent in freeing the modern mind and, more positively, in giving a direction to the intellectual fulfillment of man. The ethic of science is not the whole of human ethic but it is an important part of it, and it ought to stand out clearly and naturally in the teaching of science.

CHAPTER III

A SYSTEM OF CURRICULUM DEVELOPMENT

A. Description of the System

B. Using the Framework
    1. Goals
    2. Operational Objectives
    3. Components of Instructional Strategy
        a. Selection and Sequence of Content
        b. Selection of Instructional Media
        c. Learning Theory Related to the Goals
            (1) Acquiring Attitudes
            (2) Learning Scientific Modes of Inquiry
            (3) Learning Skills
            (4) Acquiring Knowledge
        d. Diagnosis and Evaluation
        e. Techniques

C. Seeking a Consistent Model of Science Instruction
    1. What We Mean by Consistency
        a. In Strategy
        b. In Technique
    2. Criteria for Evaluation of Illustrative Materials

A SYSTEM OF CURRICULUM DEVELOPMENT

The Framework : A System

Among the other tenets of our philosophical position set forth in Chapter I, we posited the view that the SCIENCE CURRICULUM favors a liberal education only to the extent to which the spirit of science is integrated into instructional practices. In Chapters I and II we labored to convince the reader that it is of the very nature of science to be a vital, dynamic force which cannot be imprisoned in rigid compartments, but must be allowed to develop in an atmosphere of freedom and challenge. Teacher and student alike must be engaged in this process of exciting discovery, respecting all the while nature's insistent demand for adherence to truth. It remains for us in this third chapter to suggest how the science curriculum can foster this end. For this purpose we like to think of our framework as a system: A SYSTEM FOR TRANSLATING GOALS INTO INSTRUCTION.

A. A Description of the System

Having established, as the first step in the development of this system, the philosophical principles upon which it rests, we proceed to the second step which is to delineate more specifically the goals of science education. These goals are meant to convey the intent of the science program. In order to achieve a goal, certain operational definitions of behavior must be identified. The third step, then, is to define these goals, as explicitly as possible, in terms of operational objectives. Operational objectives are behavioral descriptions of what students will be doing during structured learning opportunities. Operational objectives should strive for specificity in terms of the behavior of the learner. They include the specific mental processes, the actions, the knowledge, the emotions, and the attitudes that are inherent in the goals. The fourth step is to generate teaching strategies. Teaching strategies are more than mere lesson plans. They are ingenious ways in which the teacher conducts himself and manages the environment so as to elicit, observe, and evaluate desired behaviors in learners. They assist in distinguishing which behaviors should be reinforced and which should be ignored. They will vary with each goal, each operational objective, each teacher, and each group of learners. Finally, techniques must be selected which are consistent with the strategy. The teacher must have a repertoire of techniques which elicit desired responses and behaviors from the learner.

B. Using the Framework

Thus, we have described the framework as a system from whose philosophical foundations flow a statement of goals, a definition of objectives in operational terms, the generation of teaching strategies, and techniques consistent with these strategies. We proceed now to discuss each of these in detail so as to illustrate how the framework can be used.

We wish to emphasize at the outset, however, that what follows is meant merely to serve as a guideline to demonstrate what can result from employing this system. The list of goals and objectives is not all-inclusive, since each person who examines goals can derive many different objectives. Lack of time, space, and knowledge of local situations make it impossible to present operational objectives for all students. Only examples can be given. Educators in classrooms and schools are invited to define operationally, in as explicit behavioral terms as possible, those operational objectives which are suitable for their particular situations. From these objectives many creative strategies may be generated, and a variety of consistent techniques may be employed.

Furthermore, each goal, objective, strategy, and technique must be tried and tested to see if each is consistent with the other. Are the techniques used within a strategy consistent with the strategy? Are the strategies really allowing the learner to perform the desired behaviors? Are these behaviors really leading to our goals, and are the goals commensurate with our philosophical beliefs? Viewing the framework as a dynamic process rather than a rigid structure can facilitate a constant scrutiny of techniques, experimentation with more powerful strategies, identification of more realistic behaviors, and a better definition of goals.

1. Goals

Goals are somewhat nebulous since they are open to interpretation by many. They usually contain value-laden and somewhat ambiguous descriptions of our desires and aspirations. Because of their ambiguity they are open to interpretation, clarification, and elucidation by each person who examines them. However, goals do convey the intent of the science program. As cultural values change and society's problems become more complex, the goals need to be reassessed again and again to see if they are consistent with the organization of knowledge and with the problems and needs of the learner and of society.

Out of the philosophical foundations present in Chapter I, four goals of science education have been derived. These are:

a. Goal I: Attitudes

To develop those values, aspirations, and attitudes which underlie the personal involvement of the individual with his environment and with mankind.

b. Goal II: Scientific Mode of Inquiry

To develop the rational powers which underlie the scientific mode of inquiry.

c. Goal III: **Skills**

To develop fundamental skills in manipulating materials and equipment and obtaining, organizing, and communicating scientific information.

d. Goal IV: Knowledge

To develop the knowledge of systematic facts, concepts, and generalizations which lead to further interpretation and prediction of the natural world.

Science educators must be careful not to stress any one of these goals to the neglect of the other three. Each one of them is a necessary factor in developing a scientifically literate citizenry. This will become clear as we discuss each of these goals in detail.

a. Goal I: To develop those values, aspirations, and attitudes which underlie the personal involvement of the individual with his environment and with mankind.

Scientific thinking is not the cold, calculating sort of human endeavor which is often depicted as a characteristic of a scientist. On the contrary, much personal judgment and personal excitement enter into the picture. This is true both for the scientist in whose mind an idea originates and for his colleagues who help to elaborate it. Such creative endeavors on the part of the scientist are not too different from those of the artist or the poet. Similarities between the scientific enterprise and the so-called humanities have been pointed out in Chapter II. Teachers of science need to emphasize these similarities. At the same time, it should be pointed out that there are some differences. The scientific process tends to be basically an intellectual activity and emphasizes disciplined, rational, ordered, and critical thinking. It must at all times be open to criticism, and welcome the challenge of conflicting thoughts. Those interested in science should realize its limitations and leave room for quite different approaches to the quest for truth.

In all of this the scientist plays, as a person, a key role. He must feel the sense of awe and mystery which nature provides. Most scientists today view the natural world as an open-ended source of new discoveries. Each new theory acts as a window to the next unknown. As the scientist penetrates ever more deeply into the mystery of the atom, living matter, or the cosmos, he sees a beauty which surpasses every expectation. About this he can be passionate, and his personal involvement becomes an essential part of the motivation which drives him on to make further discoveries.

Finally, if one is to understand the nature of science, he must realize the importance of the scientific community. The productive scientist must be a part of this community; that is, he must be involved as a person with other scientists. This does not mean that he must necessarily work in collaboration with others, though that is very common, but at some point in his work he must expose his ideas to other scientists, seek their criticisms, and accept their praise. Every scientific theory is thus tested in the community of scientists. Publications, private discussions, and public meetings play an essential role in the whole process of verification and stimulation to further endeavors. It is usually said that agreement with experiment provides the crucial test for a scientific theory, but theories must also pass the test of open criticism by those working in the same area. This constant exchange of ideas with others provides a bond which draws scientists together and requires that each one carry on his work with integrity. It is important that we attempt to instill this idea into our students at every level of science education.

b. Goal II: To develop the rational powers which underlie the scientific mode of inquiry.

The science educator must keep in mind that while not all of his or her students will be active members of a scientific community, such as that described under Goal I, since some will be nonscientists, nevertheless, all will one day be adult members of the world community, and must take an active part in shaping its destiny and in meeting and solving its problems. Here, perhaps more than anywhere else, will it be necessary to have clear-thinking citizens. Here, perhaps more than anywhere else, will the habits of rational thinking acquired in the scientific disciplines shine forth most brilliantly. And here, perhaps more than anywhere else, will rational thought have its rewards in a fruitful beneficence for mankind.

How a scientist proceeds to develop his rational powers, as he probes into the secrets of nature, has already been described in Chapter II. We do not presume here to improve upon this presentation. Rather, let us examine it more closely in an attempt to extract from it a succinct summary of the scientific mode of inquiry. Our purpose here is to see how the teacher can assist his student to develop his own powers of rational thinking. Essentially, what the experienced scientist does, the beginner must do. How then does he proceed?

We see that a scientist begins with a purpose. He has made an observation, perhaps of some phenomenon within his environment, which has raised a question in his mind. He is confronted with some problem for which his mind must find an answer. He proceeds to search in his mind for this answer, some explanation for the problem before him. Sooner or later he finds one. It is only a guess at first, perhaps, a supposition, a hypothesis. This hypothesis must be subjected to the stern scrutiny of testing, of experimentation, to test the hypothesis. Experimental data is recorded, examined, reflected upon, to establish the validity, or non-validity, of the hypothesis. Generalizations are formed, the hypothesis rejected or developed into a theory, depending upon the results of the supporting data obtained from experimentation. Conclusions are drawn, further interpretations projected, new ideas spring forth, and the whole process begins over again. What has happened? Science has advanced. Where? In the mind of the scientist--so likewise, in the mind of the child. He has begun the process of rational thinking. He is learning how to draw sound conclusions from sound principles.

c. Goal III: To develop fundamental skills in manipulating materials and equipment and obtaining, organizing, and communicating scientific information.

In order to use the scientific mode of inquiry and to develop a conceptual understanding of the physical universe, the scientist uses a variety of skills. He procures data and information through his own observations and experiments, from reading, and from listening to his peers. He is proficient in the use of measuring instruments and in the construction and use of laboratory apparatus. He handles materials and equipment in a safe manner. He applies linguistic, mathematical, graphical, and tabular skills in recording and organizing data. He has the ability to interpret data and to report it in a manner that facilitates the learning of the reader or the listener. He demonstrates social and linguistic skills in working with others and in communicating ideas. If science education is to be consistent with the way scientists work, a major goal of the teacher is to provide opportunities for his students to develop and use these scientific skills.

This goal can be justified also in terms of its contributions to the personal and social goals of education. Entrance into skilled, technical and professional occupations requires proficiency in many or all of the skills mentioned above. Accountants, salesmen, bankers, managers, and social scientists, as well as engineers, physicians, nurses, and all kinds of scientists must be able to obtain, record, process, interpret, and report information, and to communicate ideas in a clear and convincing manner. The kinds and sources of information may vary, different measuring instruments may be used, and each occupation may employ its own communication symbols. The fundamental skills, nevertheless, are common to a broad spectrum of occupations. Linguistic, mathematical, and social skills contribute also to the development of competencies needed for effective citizenship.

d. Goal IV: To develop the knowledge of systematic facts, concepts, and generalizations which lead to further interpretation and prediction of the natural world.

Facts, concepts, and generalizations constitute an important segment of science. The reason for acquiring knowledge of these is not merely to develop a storehouse of facts. The major reason is that the rich store which they furnish to the memory provides the content of the coded neural messages by means of which the human mind operates. Attitudes, modes of thinking, strategies of thought are all examples of the warp of mental functioning. Knowledge is the woof. Human thought requires both.

As indicated in the discussions of Goals II and III, through the practice of inquiry skills, the student develops his own knowledge, formulates his own principles, discovers his own solutions to problems. But if knowledge were to be restricted to what the student could discover by himself, it would be a thin thing indeed. As he engages in intellectual pursuits the student must have available from his memory many facts and principles which other people have discovered and verified over many decades of scientific investigation. In this respect the student resembles the scientist, who also is dependent upon his predecessors. Sir Isaac Newton humbly acknowledged this dependence when he said: "If I have seen farther than other men, it is because I have stood upon the shoulders of giants."

Information stored in a person's memory is of two kinds: isolated bits of information called facts, and systems of classifying information which we call concepts. A series of concepts which are related and mutually interdependent are called generalizations. The Conceptual Themes which follow are generalizations. They provide significant patterns of ideas drawn from the vast storehouse of scientific knowledge.

CONCEPTUAL THEMES

Conceptual themes are used in curriculum development to help provide a means for coordinating the science curriculum from kindergarten through high school. A conceptual theme in science is a large unifying principle which represents either a series of concepts which are mutually interdependent, or a process of scientific inquiry. A characteristic of these themes is that they cut across subject matter fields and therein lies their effectiveness for integrating science courses. For example, "Energy exists in a variety of convertible forms" is a theme which runs through all the natural science diciplines, including physics, chemistry, biology, the earth sciences, and all the interdisciplinary modifications of these. In each of these subjects, and at every grade level, relevant concepts can be taught which contribute to a growing understanding of the theme with each passing year.

Conceptual Themes and the Scientist

The identification of the major themes for science education is the responsibility of the professional scientist. He is in the best position, by reason of education and experience, to identify the laws and theories which are significant for understanding the natural world. He is also the most qualified to recommend the processes of inquiry inherent in the different sciences which make them knowable. The State Advisory Committee on Science Education has used the services of outstanding scientists to establish the thematic basis of the science curriculum.

Conceptual Themes and the Learner

The learner acquires a deeper understanding of a conceptual theme over a period of years, as new interrelationships are sought and tested. For example, children in the first grade may begin to learn about energy transformation through a study of melting ice cubes. As the child grows older he can learn that when wood or natural gas burns, there is a change from chemical to heat energy, as carbon dioxide gas is given off and water is formed. Later, when he studies physics he may make quantitative studies of energy changes accompanying chemical reactions, or perhaps those which accompany atomic fission. In biology he will learn that photosynthesis is a process in which light energy is transformed, and that respiration in living organisms is a more complex example of combustion than that which he encountered as a child, when he observed wood burning and changing into carbon dioxide and water. But in all of these, he will find the same theme in a variety of contexts. At each successive grade level his new learning about "energy changes" is based upon what was learned earlier, and what he learns this year provides the insights for next year's venture with the topic. As the child moves through school, his conception of energy conversion becomes increasingly more generalizable, with a wider range of interpretive power. A conceptual theme thus may be thought of as a curriculum thread which runs vertically through the child's education, and on this thread are strung beads representing the supporting concepts developed at each grade level.

But this thread has a work to do. It simplifies, coordinates, and motivates. For through the process of seeking interrelationships and coordinating concepts into significant patterns, the human intellect becomes ordered, transcends the realm of complicated details, and is liberated in simplicity. From this vantage point the learner begins to understand that truth is one. New horizons are envisioned, and the will is motivated to explore further into the unknown. Liberal education becomes a reality, and will bear its fruit.

Conceptual Themes and the Educator

As the scientist is responsible for identifying the conceptual themes, so the educator must now draw upon these as guidelines in building the science curriculum. He must keep in mind that in each of the science subjects, and at increasingly higher levels of learning, relevant concepts should be taught in such a way as to contribute to a growing understanding of the conceptual themes. He must achieve an effective sequence to the science curriculum, building upon the student's past experiences and developing his readiness for the next phase of understanding. For the educator the conceptual themes are a means for planning the total science program in a way which will provide for an integrated sequence of learning. By identifying what is significant they provide a guide for the educator without forcing a pattern of instruction. They provide a map for determining the direction to go, without prescribing the route for getting there.

Summary List of the Conceptual Themes

It is with some hesitancy that we list the conceptual themes by title, because so little of their meaning is apparent without reading the full description. A detailed description of each theme is given in the Appendix. The reader is urged to refer to them in Appendix A.

An abridged list is given on the next page. The reader's attention is called to the fact that the first two themes on the list may be considered as the process themes and the rest as the concept themes. Such a classification of the themes reflects the two kinds of knowledge that represents science, namely, the intellectual processes, and the results of these processes, the conceptual achievements. These are interacting phases of science and each is the product of the other. As such they form two components of the science curriculum.

Conceptual Themes

THEME A: Events in nature occur in a predictable way, understandable in terms of cause and effect relationship; natural laws are universal and demonstrable throughout time and space.

THEME B: Frames of reference for size, position, time, and motion in space are relative, not absolute.

THEME C: Matter is composed of particles which are in constant motion.

THEME D: Energy exists in a variety of convertible forms.

THEME E: Matter and energy are manifestations of a single entity: their sum in a closed system is constant.

THEME F: Through Classification Systems scientists bring order and unity to apparently dissimilar and diverse natural phenomena.

(1) Matter is organized into units which can be classed into organizational levels.

(2) Living things are highly organized systems of matter and energy.

(3) Structure and function are often interdependent.

THEME G: Units of matter interact.

(1) The bases of all interactions are electrical, magnetic, gravitational, and nuclear forces whose fields extend beyond the vicinity of their origin.

(2) Interdependence and interaction with the environment are universal relationships.

(3) Interaction and reorganization of units of matter are always associated with changes in energy.

The Committee recognizes that there are other ways of describing these themes, and that a longer list might be devised. We are of the opinion, however, that these themes can be used to define the significant processes and concepts which need to be taught in the elementary and secondary schools of California. They represent what we would have the student understand about science and its processes when he graduates from high school. Thus the themes represent long-range goals of instruction.

2. Operational Objectives

Having defined our goals, the next step is to translate them into instruction by identifying them with certain operational definitions of student behavior. Our operational objectives are behavioral descriptions of what the student will be doing during a given learning period. For our purpose here we will discuss these in order, in terms of the four goals which we have already listed above.

a. Goal I

The student develops those values, aspirations, and attitudes which underlie the personal involvement of an individual with his environment and with mankind.

OPERATIONAL OBJECTIVES

(1) He is intrigued by phenomena in his environment.

Given samples of materials such as camphor and sulphur:

He points out similarities and differences in them.

He initiates simple tests to more exactly determine their nature.

He wants to measure such characteristics as density and hardness to compare his results with those in reference sources.

He investigates novel features of the substance both in and out of the classroom.

He speculates on characteristics that are not testable with his resources.

(2) He states or exhibits a preference for processing data and for building theories.

Given the problem of verifying the value of "g," the acceleration due to gravity, as 32 ft/sec^2 or 9.80 meters/sec^2:

He generates data from experiments with falling objects and pendulums.

He collects data until he can show that potential errors will be minimized.

He perceives potential errors in his experiment.

He modifies techniques to minimize human and equipment errors.

He attempts to account for discrepancies between derived and accepted values.

He investigates the importance of exact "g" determinations in man's space and earth endeavors.

(3) He applies rational thought to discrepancies and their explanations and gives reasons for his choice.

Given one egg floating appreciably higher than a second egg in a beaker apparently full of ordinary tap water:

He investigates more closely the nature of the egg and the water.

He formulates hypotheses to explain the discrepancy.

He defends his hypotheses based upon his past experiences.

He submits his hypotheses to additional tests.

He modifies or retracts his hypotheses upon discovering new information.

(4) He seeks interactions with others.

Given a collection of moths:

He shares his data and ideas.

He comments on the unusual wing patterns and he brings examples from his own collection.

He seeks and accepts criticism of his classification of wing patterns.

(5) He demonstrates personal integrity as a science investigator.

Given the opportunity to inhibit or accelerate the decay of beans rotting in a beaker of water:

He proposes to set up a carefully controlled series of experiments.

He controls his environmental variables as exactly as possible.

He records daily results faithfully and accurately.

He displays no prejudice toward preconceived notions.

He assumes responsibility for his mistakes and failures.

He incorporates a thorough analysis of his mistakes and failures in his written reports.

(6) He responds favorably to beauty in his environment.

Given the opportunity to use the microscope as a research tool:

He points out the symmetry and orderliness in cell structure.

He displays excitement from observation of microscopic life.

He wants to share his observations of crystal formation in a seeded solution.

He asks to use the microscope to observe animate and inanimate objects which he brings in.

(7) He relates science to other human endeavors.

Given an assignment to collect smog particles on vaseline-covered microscope slides:

He displays concern over the threat of smog to human and natural resources.

He discusses the asethetic value of a smog-free environment, and the economic and political considerations in the battle against smog.

He searches the literature and reports on what scientists are doing to combat air pollution.

b. Goal II

The student develops the rational powers which underlie the scientific mode of inquiry.

OPERATIONAL OBJECTIVES

(1) He senses the existence of a problem.

Given a discrepant event in which a round object rolls up an incline:

He points out elements in the event which are inconsistent with his previous experience that objects roll downhill.

He states a problem presented by the discrepancy such as: "How can this thing seem to go against the force of gravity and roll uphill?"

(2) He formulates tentative statements (hypotheses) to identify the causes of events.

Given a balloon suspended in a stream of air from a vacuum cleaner:

He uses intuition and insight as a basis for tentative explanation.

He generates novel or personal ideas about why the balloon does not fall.

He proposes alternative explanations.

He applies existing theories to explain why the balloon floats.

(3) He generates data to verify or define a theory.

Given the problem of determining whether a plant is alive:

He searches the literature to find definitions of "aliveness."

He proposes ways to test "aliveness" such as response to light and gravity.

He sets up experiments to collect the gas produced by a plant.

He compares predictions and results to establish whether he really has determined aliveness.

(4) He draws inferences from data gathered.

Given formulas and data which predict adult height and weight from teen-age height and weight:

He manipulates the formulas to achieve predictions.

He is disturbed by measurement or manipulation errors which project abnormal growth patterns.

He shares data with classmates to plot graphs and establish trends.

He suggests formula modifications of the given formulas to achieve realistic results for his particular group.

(5) He predicts events based upon his theory.

Given the basic instruments of meteorology:

He establishes relationships between today's readings and tomorrow's weather.

He predicts weather changes based upon the patterns he has observed.

He points out the limitations of his predictions due to variables he cannot measure.

He seeks data beyond his immediate environment to reduce prediction errors.

(6) He forms generalizations from the usefulness of a theory, develops new ideas, and tests them. He finds that they fit into a broader concept.

Given a photo-flash bulb to weigh before and after flashing:

He performs this experiment and finds the theory covering the conversion of matter in closed systems useful.

He looks for examples of other matter conversions in closed systems, proposes experiments to study them, and performs the experiments.

He finds that all of the examples chosen lead him to the same conclusion.

He forms the generalization verifying the principle of conservation of mass.

c. Goal III.

The student develops fundamental skills in manipulating materials and equipment and obtaining, organizing, and communicating scientific information.

OPERATIONAL OBJECTIVES

(1) He is skillful in constructing and using laboratory apparatus.

He follows directions for assembling and using apparatus.

He selects the most appropriate materials and equipment for each activity.

He maintains and stores equipment properly.

He designs and constructs apparatus for special purposes.

He handles materials, apparatus, and tools in a safe manner.

(2) He reads widely and accurately to obtain information.

He reads materials and instructions needed for conducting an investigation.

He obtains data from diagrams, charts, and graphs to apply to practical problems.

He reads descriptive information about objects and events.

He uses recognized library research skills to extend his knowledge.

He reads formulas and scientific symbols with understanding.

He abstracts major concepts and understandings from science texts, references, and current literature.

(3) He observes natural and laboratory phenomena intelligently to obtain information.

He uses a variety of senses to detect exact characteristics of objects and events.

He reads scientific instruments to extract the highest degree of precision.

He compares properties of matter to distinguish gross and minute differences.

(4) He records and organizes observations and ideas in a precise and accurate manner to enhance their usefulness.

He makes simple pictures which illustrate an object, event, or concept.

He keeps a written log of qualitative and quantitative observations.

He records quantitative data in tabular form.

He represents data graphically.

He uses precise and unambiguous language to describe observations.

He uses mathematical techniques to simplify and interpret data.

He categorizes lists of objects such as rocks, animals, and plants.

(5) He communicates with others in written and oral form using terminology which is consistent with the conventions of science.

He describes an object or event clearly, accurately, and concisely to provide a clear mental picture for the listeners.

He organizes his research into effective oral or written reports.

He formulates clear and pertinent questions and participates actively in group discussions.

He translates statements and ideas obtained from reading into his own words.

d. Goal IV.

The student develops a knowledge of systematic facts, concepts, and generalizations which lead to further interpretation and prediction of the natural world.

OPERATIONAL OBJECTIVES

(1) He demonstrates knowledge of specific facts.

He recalls that a single orange falls at the same rate as a bag of oranges does.

He uses the correct value of the speed of light in computation.

He identifies William Harvey as the discoverer of the path of circulation of blood.

He recognizes cloud forms.

He recalls that water boils at 212°F. at one unit of atmospheric pressure, (1 atmosphere or 760 mm. Hg pressure)

He recalls that dilute hydrochloric acid causes marble to fizz.

(2) He demonstrates knowledge of historical trends and sequences.

He can trace some aspects of modern scientific methods back to the Greeks' use of rational inquiry.

He can cite examples where scientific progress was arrested by restrictive dogmas and over-reliance on authority.

He demonstrates by means of examples that science provides power for technology to generate new tools which, in turn, aid in generating new knowledge.

He recognizes the problems and promises of the rapidly accelerating growth of scientific knowledge.

(3) He demonstrates knowledge of criteria.

He quotes from published and verified sources to establish scientific authority for his arguments.

He judges the validity of scientific discoveries on the basis of their being reproducible.

He identifies as a criterion the acceptance of those who are experts in the field.

He points out the necessity for freedom in scientific investigation and communication.

(4) He domonstrates knowledge of generalizations.

He describes test situations which verify that bodies fall with constant acceleration.

He draws a graph to show that atmospheric pressure is inversely proportional to altitude in the atmosphere, when other factors are held constant.

He cites crystal growth as an example of molecular structure.

He describes eye color differences in children of heterozygous parents in terms of gene function.

(5) He demonstrates knowledge of conceptual themes.

He states that the theory of evolution is related to natural selection.

He explains the heating of brake linings in terms of conversion of energy forms.

He describes a sea anemone in terms of an organized system of matter and energy.

He relates light and radar waves to each other in terms of their position in the electromagnetic spectrum.

He describes the structures of a leaf according to its specific functions and its contributions to the total system.

He predicts what would happen to the ecology and the economy of a grain-producing valley if all predators of rodents were eradicated.

3. Components of Instructional Strategy

Almost every teacher walks into his classroom with a plan in mind, that is, a logical thought-through scheme for "what we are going to do to-day." Teaching plans are based upon goals, objectives, previous accomplishments with successful techniques, and the immediate classroom conditions. But "teaching strategies" are, as we have said, more than mere lesson plans. They are ingenious ways in which the teacher conducts himself and manages the environment so as to elicit, observe, and evaluate the desired behavior in learners. They include mental maps which the teacher uses to give directions to discussions and activities toward a long-range goal. Strategies are essential to making the correct decisions in the midst of the many problems which are constantly bombarding the teacher. They assist in distinguishing which behaviors should be reinforced and which should be ignored. They will vary with each goal, each operational objective, each teacher, and each group of learners. With a strategy in mind there can be a more rational basis for decision making. The components of teaching strategy include: a) Selecting and sequencing content; b) Selection of instructional media; c) Learning theory; d) Diagnosis and evaluation; and e) Techniques. We will now consider each of these in detail.

a. Selection and Sequence of Content

There are two aspects to the selection and sequence of instructional materials: one represents the selection and arrangement of subjects for a year's study, the horizontal curriculum; the other concerns the sequencing of materials to provide the vertical structure of the curriculum from kindergarten through high school. The horizontal structure is concerned with the outcomes sought in a year's study and is planned in terms of short-range objectives. Long-range goals, those requiring years to attain, represent the vertical focus of the curriculum. The advantages gained by planning curricula in this way are coherence and maximum learning effectiveness. Repetition is minimized and concept growth enhanced; learning is maximized, and forgetting reduced. Planned in this way the curriculum is a matrix of learning experiences with dimensions within and between school years or science subjects. We recognize a curriculum to be more than a series of topics or courses. There are qualities of organization and sequencing which of themselves help to assure the attainment of the learning goals.

The conceptual themes identified in this report, by providing the vertical organization to the curriculum, give continuous direction for learning experiences. All that is to be learned in school about the "interdependence of structure and function" requires years of teaching, and at various maturity phases of the student. To fully appreciate a process such as "frames of reference" requires numerous encounters with the theme and in a variety of contexts. At almost every grade level, K-12, learning experiences are selected to enhance the meaning of this theme. It is in this way that we hope to develop depth of understanding in young people.

The specific concepts to be attained and the process skills to be developed provide the framework for science courses at each grade level. There is always more to be taught at every grade than it is possible for a pupil to master. We seek, therefore, to select those learning materials which have the greatest potential for interpreting and explaining the events and phenomena of the natural world. We seek to avoid the trivial, the out-of-date, and unscientific concepts and processes.

Valid scientific concepts, as well as valid modes of scientific inquiry, are essentials of the curriculum. However, to be meaningful to the pupils, the analogies and applications of science must be directed to situations or phenomena which are familiar to them. For example, the concept, "there is an interaction of living things and their environment," may be conveyed to children by using snowshoe rabbits as the object of study in the northern high Sierras; starfish and sea urchins in tide pools, for children living along the coast; cactus and lizzards, if they live in the Mojave Desert. Making use of local materials is more a question of teaching strategy than it is of curriculum.

The selection of science concepts and processes needs to be done, recognizing the developmental phase of the learner, in terms of his intellectual, social, motivational, and educational levels of attainment as described by the instructional goals. The sequence of subject matter in a grade or course is of a hierarchial nature, beginning with topics or processes that are essential to understanding the next range of meaning. Each time a topic is taught, it is built upon what has been learned before and creates the "readiness" for the next step. In part, the sequence of learning materials is dependent upon the components or contributing concepts derived from the discipline which makes the next steps in learning reasonable and more deeply meaningful. For example, a pupil needs some understanding of an energy cycle, a few simple concepts of chemistry, an acquaintance with light phenomena, among other things, before he can begin to appreciate the process of photosynthesis at the tenth grade level. Sequencing has a component in the developmental characteristics of the learner, as well as in the conceptual structure of the discipline.

The sequencing of the process skills is dependent upon the meaning they will have for understanding certain concepts and upon the next learning step needed to make the inquiry more powerful. We may expect higher degrees of efficiency if there is some regard as to how other subjects in the curriculum are paced. Mathematics and science, for example, can be sequenced in a way which is mutually beneficial.

b. Selection of Instructional Media

The importance of multi-media instructional materials to do the best job of teaching young people is a long established principle of education. However, the problem is not simply one of a greater variety of media but how these materials may be linked to the curriculum, to methods of teaching, to school organization, and most important of all, to the improvement of learning in terms of the stated goals of the science program. Too many innovative instructional materials--closed-circuit television, loop films, transparencies, open-ended laboratory experiments, supplementary pamphlets and others--stand alone, with the result that we have a wave of enthusiasm for each new piece of equipment without regard to its educational effectiveness. The value of a teaching device is that it makes a positive contribution to the improvement of pupil learning.

Educational technology also needs to be considered in terms of making the teacher's task more efficient and effective. What is required is a systems concept in which the goals of science teaching, the curriculum, the modes of instruction, the characteristics of students, and ways of learning are brought into harmony with school organization and with the machinery of education. In planning the accouterments of education, a consideration of the acts of learning must come first.

There are many kinds of learning, such as, forming concepts, acquiring skills, developing attitudes, using inquiry process, and others, each demanding somewhat different conditions. Supporting educational media will not, therefore, be equally useful under all these conditions. To fully understand living organisms requires that one work with living, not preserved, specimens. A skill is best acquired by engaging in activities that require it to be used; lectures on skills are not very effective. Concepts are more likely to be retained longer when experienced in a variety of contexts, for example, through an experiment, an observation in the field or on film, a lecture incorporating good analogies, and extensive reading. Media of instruction should be selected at the time the science curriculum is under development, and should be specific to the learning sequence that is planned. This could result in the establishment of learning "packages" which harmonize teaching goals and instructional media. The expected outcome would be pupil learning at maximum efficiency.

c. Learning Theory Related to the Goals

Teaching strategies encompass what is known about learning theory and acceptable pedagogical methods. They take into account general principles of learning such as sequence, motivation, reinforcement, and the transfer of learnings. As suggested in Section B.3 above, the strategies applied to the attainment of each of the four goals are different. What the teacher does to establish desirable attitudes in students will be different from what he does to develop broad conceptual understanding. The present section will describe what learning theory says about how attitudes, skills, use of scientific mode of inquiry, and knowledge are acquired, how instructional procedures might be used to implement the theory, and what implications they have for selection of content and materials.

(1) Acquiring Attitudes

An attitude is a mental disposition inferred from the choices made by an individual. The choices implied by this goal of science education include those of choosing evidence which is scientifically based, choosing to credit statements made by scientists within their field of competence, choosing scientific activities as having high social value, choosing science as a satisfying field of human endeavor.

There is much evidence to show that attitudes are almost never acquired by means of verbal communication *per se*. In other words, exhortations such as "Be careful," "Be honest," or "Value science" are almost certain to be extremely unsuccessful. Attempts to establish favorable attitudes toward science by such techniques as these are therefore unlikely to be of much use. However, this is not to suggest that verbal communication does not have a part to play in acquiring attitudes. According to evidence, effective communication for the acquiring of attitudes must occur in a context which is subtly tuned to the motivation of the individual.

Positive attitudes toward science are likely to be acquired under conditions in which: a) the learner relates his own choices to those made by other people (especially adults) whom he seeks to emulate, and b) the learner experiences success in carrying out scientific thinking and other scientific activities. It will be apparent that both of these conditions pertain to the motivational development of the individual. In the first case, one is dealing with the kind of motivation related to becoming an adult and to the individual's life goals. In the second, it is a matter of developing an increasingly strong attachment to varieties of human activities which provide pleasure. The practical implications of this for teaching strategies seem clear:

(a) The student needs to interact with teachers, and with others who perform instructional roles, who do themselves derive pleasure from scientific activities and modes of thought. Their enjoyment will be communicated to the student and he will tend to acquire this attitude.

(b) Science instruction needs to be designed to provide "success experiences" in science activities from the earliest grades onward. In the beginning, the child can achieve success with such relatively simple tasks as classifying objects by their properties. Later he may come to experience the intense pleasure of the scientist in seeing how data "fit" his hypothesis.

(2) Learning Scientific Modes of Inquiry

Learning to think scientifically would seem to be primarily a matter of practicing thinking under conditions in which problems grow progressively more complex and the activity becomes progressively more independent of outside help. Initially, the child may learn to think out problems in only a partial manner. For example, he may practice deducing the consequences of some theory which is given to him and which have previously been defined and described for him. Ultimately, one wants the student to learn to look at a brand new phenomenon, make his own observations and hypotheses, decide how to test them, carry out the verifications and interpret his findings. What is desired, in other words, is that the whole new problem be solved by means of the scientific mode of inquiry.

Some teaching strategies important in the development of the scientific mode of inquiry would be:

(a) Create classroom situations in which the students actively participate in scientific investigations. Situations should be provided where they must use scientific inquiry in arriving at solutions to problems. For instance, they may be presented with a discrepant event from which they propose a hypothesis which explains the event; they suggest ways in which they might test their hypothesis; they set to work to test it experimentally; they draw conclusions from their results; and make predictions from them. They will not learn the scientific mode of inquiry by merely discussing it or memorizing its components.

(b) Gradually introduce increasingly complex and progressively more undefined problem situations. It seems likely that going too fast would lead to some undesirable consequences, as for example: 1) dependence upon "hunches" which have an inadequate basis; 2) formulation of hypotheses which are not satisfactorily tied to reality by means of operational definitions; overgeneralization of experimental investigations whose conceptual framework is inadequately understood.

(c) Build upon a prior acquisition of some simpler intellectual skills or processes. If the student is to carry out comprehensive thought processess in solving a problem, he must first have learned such skills as making observations, recording, organizing, interpreting, et cetera.

(d) Build upon the prior acquisition of facts, concepts, and generalizations. While it is true that thinking can be done without relevant knowledge, the systematic thinking of science cannot be. Virtually all accounts of scientific thinking emphasize the importance of great amounts of relevant knowledge on the part of scientific thinkers, including those who have made great discoveries. Accordingly, practice in the use of scientific modes of inquiry needs to be carried out by students who have already acquired relevant knowledge of the phenomena about which they may be thinking. Thinking cannot be truly productive when it results in conclusions, which, while in some fundamental sense are rational, may nevertheless be incongruous with empirical observations, or with reasonable inferences based upon them. The scientific mode of inquiry takes place in a context which is rich with potentially relevant facts, concepts, and generalizations.

(3) Learning Skills

The mastery of the scientific mode of inquiry and the development of the skills required in science go hand in hand. In deciding how to teach a skill, a teacher should make an analysis of its elements and the contribution it can make toward acquiring other skills. The following points should be kept in mind:

(a) Development is gradual and somewhat sequential.

Even a simple skill may require considerable practice before competence in it is achieved. Moreover, one cannot expect a child to be competent in reading formulas and symbols peculiar to science before he has learned the more fundamental skill of reading in general. Likewise, competence in mathematics must often precede competence in natural science. This does not mean, however, that the child needs to be proficient in reading and mathematics before he begins to study natural science.

(b) Repeated demonstration of a skill makes mastery easier.

Learning a skill is generally more efficient if the student has an opportunity to observe a specific demonstration, or a series of them, by a skilled worker. Even better is the demonstration which is followed by an opportunity for the child to attempt the skill, particularly if the demonstration by the expert and the attempt of the student follow each other in a series of alternate demonstrations and trials.

(c) Practice must be provided.

The ideal way to furnish the opportunity for practice is to allow the student or child to apply his skill to a real problem. Thus the motivation supplied will enhance his interest to the point that he will want to continue to practice until he has achieved skill. For example, an exercise in merely weighing metal blocks soon loses its power to interest. Yet, if the problem presented calls for skill in weighing accurately in order to determine the cause for different buoyant effects in otherwise apparently similar metal blocks. the child will be more likely to persevere to the point of achieving success in making accurate weighings.

(d) The advantage of acquiring the skill must be made clear.

An older student is perhaps aware of the saving of time and effort which follow upon the efficient application of a skill. The younger child may only realize that "if he doesn't do it right, it may break." He needs to be helped to find the purposes of a skill, through discussion or analysis, or some other means.

(e) The need to verbalize about the skill should be recognized.

This gives an additional means of remembering, and also gives him an opportunity to communicate with others about his actions.

(f) The highest order of attainment in developing skills is that of building one's own skills, or modifying them in the face of new or unusual needs.

Open-ended activities should be provided for the student who has mastered certain skills to vary them or re-make them to fit the new requirement. For example, for the student who is proficient in weighing and in calibrating homemade instruments and at interpolation, the problem of getting more precise values from an overstretched spring balance is a challenge to improve his skills by applying a combination of them in a variation which initiates or gives practice in a new skill.

(4) Acquiring Knowledge

As described in the discussion of Goal IV, one can think of a person's total thinking mechanism as consisting of a storage system, an interpretive system, and an orientation system. Information retained in the storage system consists of facts and concepts, and the interpretive system uses concepts and relations among concepts to formulate generalizations.

A concept is a category which a person uses to classify the stimuli which he observes. We infer that concepts have been learned when we see a person classify objects into categories. We can test directly whether or not a person has a concept by placing him in a situation where he is presented with different stimuli and asking him to categorize them. Very clear examples of concepts as sets of defining characteristics are the biological classificatory systems in which plants and animals are grouped on the basis of common characteristics. In sorting into categories, the individual attends to some characteristics of what he observes and ignores others. The characteristics to which he must attend are those relevant to the defining characteristics of the concept he has available. To learn a concept, a person must learn both its defining characteristics and the range of values which each of these characteristics may take. For example, if the leaves of one kind of tree are described as having four points, we want to know whether these leaves may be found with three or five points.

Given the description of a concept presented above, it is useful to think about how persons learn to distinguish among characteristics of difference concepts and how they learn to associate characteristics in sets for particular concepts. Let us conceive of a person as an information processing system in which previous information influences which has come to him is stored. This previously acquired information influences how new information is processed by causing the person to attend to some aspects of the information available, and to ignore others. We also know that this prior information influences how incoming information is interpreted and evaluated. A person's set of concepts determines how he classifies new information and how he relates it to his already acquired information. Thus, concepts are the "elements" of the thinking process.

The following are some implications for instruction in the learning of concepts and generalizations:

(a) Concept learning is achieved when the student can use concepts in the following ways:

1) Recognize what is an example of the concept and what is not. To teach concepts, we provide, in some systematic way, examples and non-examples of the concept until the learner can distinguish between the two. For example, suppose the teacher is trying to convey the concept of a pure substance to a student. She could list on the board a few examples of a substance, as well as a few examples of non-substances (mixtures). Then call upon the student to suggest a few more of each, and check to see if they are placed in the correct category.

Substance	Mixture (a "non-substance")
carbon	coal
sodium	petroleum
copper	bread
sugar	cake
salt	chalk
pure water	steel

2) Relate concepts to each other in formulating and using generalizations.

For example, the learner has grasped the meaning of the concepts, "force," "attraction," "inversely," et cetera, when he understands and can use the generalization: "The force of attraction between two objects is inversely proportional to the square of the distance between them."

3) Apply a concept to a new situation.

If a student understands the concept that K.E. $=\frac{1}{2} mv^2$ for gas molecules, he should be able to apply the same concept to determine the kinetic energy of electrons in photo-emission.

4) Develop analogues of the concept.

If the concept of homeostasis has been learned, then the student could suggest a variety of systems analogous to homeostatic systems, for instance, the operation of the thermostat, the balance of nitrogen in nature, the relative constancy of composition of the atmosphere, and so on.

5) Explain observations in his environment using the concept.

The odors of food cooking carried throughout the house, the wilting of plants, the spreading of color throughout a glass of water when paints or crystals are added, would be interpreted in terms involving the concept of diffusion.

6) Solve problems using the concept.

If he understands the concept of simple proportion, he can use it to solve problems in which direct or inverse proportions apply.

(b) We cannot give the learner his concepts and generalizations. We can provide an environment which is favorable to their development. Some suggestions follow:

1) As with concepts, the learning of generalizations can be facilitated by exposing the learner to instances where the generalization applies and to instances where it does not. Since people learn more quickly from positive than negative examples, the recommended sequence is a series of positive examples of the concept or generalization, interspersed with negative, the latter being used to check for accuracy of conceptualization.

2) Generally, it is more efficient to proceed from simpler concepts to more complex concepts when there is a relation along a line of difficulty or level of abstraction. When a child learns the concept of "hammer" and "screwdriver," he learns that they are tools for certain kinds of work. A more complex concept such as "woodworking tools" requires the student to learn what distinguishes this category from that for other kinds of tools. In learning the lower level concepts, he has learned what these distinguishing characteristics are, although he has not learned to use them with respect to the superordinate category. Learning is facilitated when the learner has to process less information at each learning attempt. Thus, learning the simpler concepts first reduces the amount of information needed to grasp the distinguishing characteristics of the more complex concept.

3) Use the concept in a variety of situations. The difficulty of learning to apply a concept to a new and unfamiliar situation is decreased if

illustrations are provided. The extent to which a student can apply what he learns in school determines the value of his formal education to his future life, and he needs help in learning how to do it.

4) The more the learner has to use a concept, the more firmly established it becomes in his thinking. Repeated use of a concept in a variety of contexts requires him to learn the many variations of characteristics, and the repeated use fixes the concept more firmly in memory.

5) In presenting examples of a concept to a learner, any arrangement that highlights the relevant characteristics facilitates learning the characteristics. Simplified diagrams, models, cueing devices all help to call the learner's attention to the significant aspects of the stimuli which are used in categorizing them.

d. Diagnosis and Evaluation

A strategy will be constructed in such a way as to elicit behaviors which the teacher can observe. These behaviors will allow the student to demonstrate how he is processing and using the concepts and generalizations which he has internalized. Inferences drawn from observing these behaviors can serve as information about the student's attitudes, readiness, level of understanding, experimental background, cognitive style, social awareness, etc. For example, the teacher can diagnose and evaluate the success with which positive attitudes are being acquired by observing the interaction between teacher and student, or student and student, initiative in working on their own, experimental integrity, desire to continue the study of science, and so on. Likewise, their progress in using the scientific modes of inquiry can be evaluated by observing the behavior of students as they engage in solving problems which require the use of the scientific mode of inquiry. Moreover, the attainment of skills of manipulation and communication is relatively easily evaluated by observing when the student can complete a task using an effective technique in an acceptable manner. Such observations help the teacher in formulating further teaching strategies. All this requires an attitude of listening on the part of the teacher. In order for the diagnosis to take place, the teacher must gather information about the child by allowing him to put forth his ideas, and listening to him. By thus allowing the child to expose his thinking the teacher can tell when he is ready to accept new information and build new concepts.

The teacher must be able to step back and analyze objectively the quality of his teaching strategy as a means of achieving the operational objectives. By comparing alternative strategies and appraising the quality of his decisions, he will possibly change his strategy on a future occasion in order to achieve his objective more effectively.

e. Techniques

Within each strategy the teacher must use techniques which are consistent with that strategy. Techniques refer to the procedures which the teacher uses to cause the learner to behave in desired ways. They are the overt tactics which a teacher employs to motivate, question, reinforce, elicit, encourage, observe, diagnose, interpret, prescribe, reject, et cetera. They are the manifestations of teacher behavior through which he performs various transactional roles with pupils. Techniques comprise the interactional processes between teacher and students, students and students, as well as teacher, student, and subject matter. Techniques include such behaviors as asking questions, lecturing, giving directions, calling upon students, praising them, utilizing students' ideas, discussing with groups, and reprimanding pupils when necessary; The techniques employed must be consistent with the form and structure of the strategy.

Seeking a Consistent Model of Science Instruction

1. What We Mean by Consistency

The essence of the change in modern science education is the search for consistency. Consistency means that our classroom teaching and the resultant learning in science education is: 1) consistent with the nature of science; 2) consistent with learning theory so that our teaching strategies take into account how learning takes place--significant learning which is durable, transferable, and powerful; and 3) consistent with the developmental level of the learner at the time. These three elements (and there may be others) should serve as bases from which teaching strategies and techniques are developed, as well as the criteria against which they are evaluated.

a. In Strategy

To be consistent then, our teaching must incorporate opportunities for the students to perform some of the same type of processes that the scientist performs. The child should be given the opportunity to make observations, process his raw material into data, develop mental models which explain discrepancies in what he has observed. Of course, the level of sophistication in carrying out these processes will vary widely. But no matter what the level of sophistication, the child can subject his ideas to the rational processes of inquiry. He can seek to determine the extent of the match between his idea and the facts he has observed. Through this process he can come to understand something of what science is for the scientist as well as understand the power of his own intellect.

Research in learning has repeatedly demonstrated that learning takes place best when the child is actively involved in learning for himself. Psychologists have shown that durability in learning occurs when children induce their own generalizations. We know that generalizations are most transferable when learners build their own. We know that students think when they encounter an obstacle, difficulty, or puzzle in a course of action which interests them. The process of thinking involves designing or testing possible solutions for a problem as perceived by the student. A course of action which runs smoothly requires little or no thinking. Objects or events which are discrepant invite the student to seek meaning.

We know that different types of learning do not take place in isolation. Attitudes, cognitive processes, skills and concepts cannot easily be compartmentalized. Rather, they are learned as a totality of human experience.

Our intention here is to emphasize the need for the generation of teaching strategies which are consistent with what research shows about learning. Generally, what we seem to know about learning indicates that the learner must be active--actively engaged in the learning process--not passive.

Knowing where the learner is in his development must be an integral part of the teaching process. This need to know the developmental level of the learner places heavy responsibility upon the teacher to perform the function of diagnosis. Diagnosing means recognizing and identifying certain symptoms of overt behavior which indicate the status of the learner with respect to some standard or norm, or his deviation therefrom. This, therefore, implies that there is some kind of a norm or developmental sequence of intellectual growth along which children proceed as they mature. Piaget, Bruner, Vygotsky, and others have given some insight into this development. They say that the development of intellectual capacity goes through a number of stages whose order is constant but whose time of appearance varies both with the individual and with society. Basically, they say that before learners can deal with abstract, propositional, theoretical, symbolic ideas, they must confront them on a concrete operational level. That is, they must interact directly with objects, using the senses as well as using logic. Prior to this stage the learner deals with objects and ideas on an intuitive level, building experiences and perceptions, but not being able to use rational thought.

What this seems to indicate for our teaching strategies is that it is useless to attempt to introduce new ideas in an abstract, theoretical, symbolic form without making sure that learners have had some experience with the concept in its concrete form as well. It also means that a large part of our teaching strategy needs to be for the purpose of diagnosing, and particularly of diagnosing to find where the boundaries lie between what the learner knows and what he does not know.

A teaching strategy incorporating diagnosis would be so structured as to call upon the younster to yield information about his own levels of readiness, his own storehouse of knowledge, and his cognitive style. This information would then be used by the teacher to prescribe other learning strategies in which a successful learning could be maximized.

Consistent teaching strategies, then, would incorporate at least these three elements: 1) classroom behavior in which students would be performing some of the same processes as the scientist; 2) learners who are actively engaged in the learning process; and 3) teachers diagnosing behavior so that younsters could operate at levels which are appropriate for their individual development.

b. In Techniques

Within each strategy the teacher must use techniques which are consistent with that strategy. For example, if a desired behavior is to have children identify problems to be solved, then what techniques can the teacher use to cause him to realize a problem exists and to identify it? One tecnique might be to provide a focus on objects and events in which problems and discrepancies are apparent. The teacher would not present problems. Rather, he would present events and objects which lead to problem identification.

If, on the other hand, a desired behavior is to have children form and test hypotheses, then we would want to have strategies which would encourage their formation. One technique might be to withhold teacher-made inferences or generalizations. One of the tasks of learning in science is for the learner to form his own inferences and generalizations. For the teacher to provide these is to rob the child of the opportunity to develop his capacity for learning the scientific mode of inquiry. The teacher should help the student draw the inferences, but not draw them for him.

If the desired behavior is model building, then teachers would use a technique of withholding praise for any one student's model. Any model which a learner generates would be respected because it is a product of his cognitive processes, and he should be allowed to work with it, fail by it, make the statement he is thinking and then correct his own thinking. The child should have the freedom and responsibility to discover his own model's degree of power to explain or predict.

Another technique of the teacher in his strategy would be to provide a rich source of information whenever the student seeks it. He could also provide directions about finding such information when it is needed. Or, he could, when appropriate, provide labels and names to help identify objects. He could provide information as to the properties of objects and the conditions under which certain phenomena occur. All of these techniques facilitate the act of learning on the part of the student.

In order for diagnosis to take place, the teacher must gather information about the student. This requires, as we have said earlier, listening. Allowing the student to put forth his notions provides the teacher with valuable information as to how children perceive the problem. It serves as an opportunity to find out what kind of past experiences he has had. It allows the teacher to see the degree of clarity of thought processes which the student is using. It gives an insight into the student's cognitive style. It is possible that the teacher will decide that the student needs to revisit the problem again on a concrete level, if he has difficulty with an abstract problem. In any case, by allowing the student to expose his thinking the teacher knows when the learner is ready to accept new information and build new hypotheses.

Naturally, not all will be able to perform these operations immediately. Teachers should recognize individual differences, but they should also strive for increasing autonomy on the part of the student. Autonomy means that the student is capable of directing his own learning, evaluating his own progress, perceiving problems himself, and offering possible explanations or solutions for them. Perhaps at first there will be marked dependence upon the teacher. However, gradually there should be a shift toward greater and greater independence of thinking on the part of the student.

2. Criteria for Evaluation of Illustrative Materials

In the section which follows, illustrative strategies and materials are presented. As they are reviewed, they should be evaluated in terms of their:

(a) consistency with the nature of science
(b) basis in learning theory
(c) appropriateness to the learner's level of development.

Some of the characteristics which will meet these criteria are:

b (a) a clear statement of objectives
(b) appropriate use of instructional media
(c) provision for differences in rate and level of learning
(d) relation to a conceptual theme
(e) techniques consistent with the strategy.

CHAPTER IV

TEACHER EDUCATION

A. Need for New Design in Training Programs for Science Teachers

  1. Change in Role of the Science Teacher

  2. Qualifications of a Science Teacher

B. Program of Preservice Education for Teachers of Science

  1. Preparation in Science

    a. Current Preparation in Science

    b. Recommendations for Improving Current Preparation in Science

  2. Preparation in the Liberal Arts

    a. Specific Attributes of Teachers of Science Expected from Preparation in the Liberal Arts

    b. Recommendations for Improving Current Preparation in Liberal Arts

  3. Preparation in Professional Education

    a. Specific Attributes of Teachers of Science Expected from Preparation in Professional Education

    b. Recommendations for Preparing Science Teachers

C. Continuing Education for Teachers of Science

  1. Role of Continuing Education in the Change Strategy

  2. Goals and Objectives for Continuing Education Programs in Science

  3. Responsibility for Planning and Conducting a Program for Continuing Education

    a. District-Sponsored Programs

    b. County or Regionally-Sponsored Programs

  4. Relative Effectiveness of Different Types of Continuing Education Programs

TEACHER EDUCATION

A. Need for New Design in Training Programs for Science Teachers.

1. Change in Role of the Science Teacher.

The changes in the science curriculum proposed in Chapter III imply a corresponding change in the role of the teacher. In his new role, the teacher at all grade levels is a guide in leading the student not only to discover what the universe is about but also to discover his powers of rational thinking, to develop them, and at the same time to develop those attitudes and skills which will ensure his personal involvement with his environment and his fellow men. Seen in this light, the teacher must be a person who is aware, not only of his great privilege in serving as such a guide, but also of his responsibility to be qualified to fulfill such a role. Equally great is the responsibility of those who are engaged in preparing elementary and secondary teachers of science. The dynamism implied in the teaching of science requires that professional educators continually reassess and redesign their programs of preservice and continuing education. In doing this, they should keep in mind that science is a basic and essential component of liberal education. Only when science is recognized by educators everywhere as an essential element of present-day liberal education can our hope for the translation of goals into instruction be fully realized. Changes, then, are called for in all areas of teacher preparation--science, liberal arts, and professional education--if the new goals and teaching strategies of science education are to be achieved.

2. Qualifications of a Science Teacher.

Programs for preservice preparation and continuing education of teachers of science can be formulated only after the major desired qualifications of the teacher have been specified. The qualifications required for a guide who creates situations in which students engage in concept-seeking, through their active participation in scientific investigations and inquiry, are quite different from those required for a reporter of facts, which are the products of investigations made by someone else at some earlier time. What, then, are these qualifications? We list some of them below:

a. Those directly related to the teaching of science.

(1) Awareness of goals and operational objectives of science.

(2) Ability to design teaching strategies.

(3) Ability to evaluate effectiveness of instruction.

(4) Ability to use and transfer skills.

(5) Requisite depth and breadth of knowledge and understanding of scientific facts, concepts, and generalizations.

b. Those indirectly related to the teaching of science.

(1) Breadth of interest in areas outside the field of science.

(2) Ability to communicate with students, fellow teachers, and parents.

(3) Scientific attitude of open-mindedness.

(4) Ability to work effectively and harmoniously with others.

(5) Willingness to test and evaluate innovative ideas and procedures.

(6) Enthusiasm for science in professional and community life, as well as in the classroom.

(7) Willingness to consider and respect the needs and views of individual learners.

It does not seem necessary here to consider each of these in detail. The meaning of many of them is obvious. However, we will discuss briefly those which most particularly apply to the new emphasis placed upon the role of the science teacher.

The four goals and operational objectives of science instruction have been discussed in detail in the previous chapter. The teacher should be cognizant of them and aim to design teaching strategies to achieve them. He should demonstrate an ability to select course content and instructional media in terms of their effectiveness for attaining these objectives, and to adapt these to the learning abilities, interests, and social needs of his students. He should be able to establish the proper sequence in his total course content, as well as in his daily lesson plans. Proper sequencing may require close collaboration with his fellow science teachers in order to generate a comprehensive and logical sequence for the total science curriculum. Courses and curricula which are psychologically sound provide for cumulative learning and are interrelated with other disciplines. When teaching strategies and techniques do not produce the desired results, the teacher should be able to recognize this, through an effective evaluation of his instruction, and he should then modify his strategy. He should demonstrate some degree of proficiency in the skills, namely, the process and manipulative skills which are peculiar to the discipline and grade level taught.

B. Program of Preservice Education for Teachers of Science.

1. Preparation in Science.

It is to be taken for granted that the preparation of science teachers will be so directed as to develop the qualifications which we have listed in 2-a above. Unfortunately, this has not always been the case in the past. Nevertheless, it is incumbent upon those preparing science teachers to ensure that these requirements are met. Moreover, each individual teacher should have the intellectual honesty and moral integrity to acknowledge his incompetence, if he is lacking these qualifications. In that case, he should not accept the responsibility of guiding young students, who have every right to be led along the paths which lead to truth, until he has prepared himself to meet these qualifications. Occasionally, of course, because of unexpected circumstances and local emergencies, it is necessary for some to teach science who do not meet these qualifications fully. However, this should be the exception rather than the rule. Teachers and administrators alike should not allow an emergency situation to become a permanently accepted regime.

We might mention here just a few examples of what we mean by the qualification listed in 2-a-(5) above, namely, "requisite depth and breadth of knowledge and understanding of scientific facts, concepts, and generalizations," and also in 2-a-(4), "ability to use and transfer skills." We stress these, not because they are more important than the others necessarily, but because it is precisely here that the unqualified teacher is most frequently deficient. We mean that the science teacher should have a thorough understanding of the basic concepts and conceptual themes, the facts, and significance of them. He should be well versed in the scientific terminology appropriate to his particular subject matter. He should be able to demonstrate proficiency in the manipulatory skills of his field(s), such as dissection, preparation of cultures, preparation of solutions, setting up simple apparatus, and so on. No small part of his preparation should be devoted to the development of skill in mathematics, since he should be able to perform the mathematical calculations appropriate to his field(s). This is particularly true for the physical science areas, which are so closely dependent upon, and interrelated with, mathematics.

a. Current Preparation in Science.

(1) Elementary Teachers.

Typically, the elementary science teacher is a nonscience major who takes several (usually three) undergraduate science courses to fulfill general education requirements for college graduation. Usually the nonscience major takes "survey" courses in which the emphasis is on verification and replication of already known information, rather than on active performance and discovery by the student. There is usually only one laboratory requirement among the science courses taken. The predominant teaching techniques are lecture and demonstration. There is little opportunity for the student to develop experimental precedures, gather and analyze data, and formulate concepts.

(2) Secondary Teachers.

The secondary teacher is a science major (or minor) who selects from the same courses as all other science majors (in a particular field) in order to fulfill the major (or minor) requirements for graduation. Typically, the student who majors in one of the sciences takes courses in depth in that field, for example, biological sciences. If he takes a minor in one of the other sciences, for example, chemistry or physics, he may also receive training in some depth in this science. If his minor is in some discipline other than science, the courses he takes to fulfill the science general education requirement might be the same survey courses taken by the nonscience majors. It is generally assumed that the upper division courses taken by the science majors should provide opportunities for the student to engage generally in the scientific process, that is, to initiate problems independently and to set up controlled experiments. However, in actual practice, such opportunities are rarely provided in most upper division undergraduate science courses.

b. Recommendations for Improving Current Preparation in Science.

(1) Course work should provide experience with investigatory procedures in order to develop the process skills the student will be expected to use in his own teaching.

Elementary: All preservice science courses should offer laboratory experiences. The laboratory work should include experiments using inquiry processes. If it is impractical to provide laboratory experiences for all nonscience majors, then the students planning to teach science on the elementary level should be separated from other nonscience majors, in order to ensure the laboratory experience and training for those who will actually teach.

Secondary: Special courses should be designed, or existing courses modified, to assure that investigatory type laboratory experiences are included with the major or minor requirements, especially for those who plan to engage in teaching science on the secondary level.

(2) Courses or sequences of courses which are organized around, or otherwise emphasize, conceptual themes should be included in the science preparation.

Elementary: The laboratory courses described above could be based on broad concepts, thus fulfilling both objectives of developing conceptual understanding as well as some degree of proficiency in the process skills. The process skills should be introduced and practiced as needed in developing the concepts.

Secondary: "Core curricula" for majors, based on concepts, are being developed in some colleges and universities. Such a basic core of courses taken over the four years of undergraduate work would encourage conceptual understanding. A "capstone" course offered in the senior or graduate year that focuses upon the major ideas, concepts, principles, laws, theories, and apparent future directions within the discipline should be provided; a major purpose of this course is to provide a coherent and logical view of the discipline.

(3) Courses should provide whatever degree of *depth* is needed to insure both concept and process skill learning, even if the scope or *breadth* of instruction must be reduced. The concepts taught at the secondary level will be more comprehensive, and the processes more refined than at the elementary level. This implies an increase in both breadth and depth of subject matter preparation for the secondary teacher. But in both cases, *the selection of subject matter should be made in the interest of how it contributes to an understanding of conceptual structure and inquiry processes of the science being taught, rather than how successfully it surveys the field(s)*.

(4) Courses should provide for students' individual differences.

This may be accomplished through construction of programmed materials, open-ended activities, varied reading lists, special sections, and individual laboratory stations such as those used in the audio-tutorial system developed at Purdue University.

(5) Courses should stress practical and social applications.

For instance, what are the philosophical implications of planned mutation of genes? What may be the consequences of the changing composition of the atmosphere?

(6) Instruction should be provided which emphasizes the history and philosophy of science; the impact of science on society and on the culture; the interrelations of science, research and technology; the relation of science to the humanities and to the economic development of a country.

(7) College science departments should employ some instructors who are qualified as "generalists" in their science fields.

Through personal interest and training, these professors tend to be concerned, more than the "specialist," with broad relationships and unifying principles within and between disciplines, and in developing teaching methods that are consistent with learning theory. Such faculty members could:

(a) Organize and administer the kinds of courses suggested in the foregoing recommendations.

(b) Serve as models in demonstrating the kinds of instructional procedures which are consistent with the goals of science teaching. Teachers often teach as they were taught. If they were taught by the lecture method, they will teach by the lecture method. Prospective teachers must see the recommended procedures in operation and see that they work, to be convinced of their value and feasibility. Such teaching demonstrations would show, for instance, that the lecture is just one of many techniques and should be used with discretion if the learning and retention of inquiry skills are major goals of science teaching.

(c) Keep abreast of new developments in their teaching field, such as the new "Computer Aided Instruction," and devise new techniques for more effective ways of presenting their material through their own personal invention.

(d) Conduct research in science teaching. For instance, the effectiveness of a "systems approach" to teaching, involving special texts, specially designed laboratory materials, programmed instruction, films and other audio-visual aids, special readings, instructors' guides, and evaluation techniques, should be investigated.

(8) The establishment of departments of General Studies in Science, with the same status and autonomy as other departments within divisions or schools, should be encouraged, where that is possible. The responsibility for developing the kinds of experiences for both elementary and secondary teachers described in the foregoing recommendations could be assumed by such a department.

2. Preparation in the Liberal Arts.

a. Specific Attributes of Teachers of Science Expected from Preparation in the Liberal Arts.

(1) Ability to use the skills and attitudes of the educated man in observing and interpreting the world about him.

(2) Ability to interpret the present in terms of the past.

(3) Effective use of the skills of oral and written communication.

(4) Ability to explain to his students the relations between science and other aspects of human endeavor.

(5) Familiarity with modes of inquiry used in other disciplines and in seeking solutions for interdisciplinary problems.

b. Recommendations for Improving Current Preparation in Liberal Arts.

(1) The training in the liberal arts should be broad. The greater the opportunity the student teacher has to investigate other parts of the knowledge and skills of mankind, the more able he should be to see science in its proper perspective and interpret it for his students.

(2) As in his major study, he should have opportunities for investigation. This is not usually provided in survey courses. Such investigation would permit the student to relate other fields to science and to form conclusions which he can test against authority and other fellow students. He should have practice in interpreting science in relation to other fields in order to help his own students interpret it for themselves. The trend in some colleges for faculty members from philosophy, history, English, sociology, and other departments to interchange ideas and collaborate closely with members of the science faculties, for the purpose of unification and identification of interrelationships, is to be encouraged.

3. Preparation in Professional Education.

a. Specific Attributes of Teachers of Science Expected from Preparation in Professional Education.

Upon completion of his preparation in professional education, the prospective teacher should be able to:

(1) State in behavioral terms the specific and long range objectives of science education.

(2) Demonstrate skills in selection of materials for instruction and evaluation by preparing a plan for a unit of work with evaluation instruments consistent with stated objectives.

(3) Plan lessons so that time allotted is proportional to the effectiveness of the activities selected.

(4) Provide his students with the rich environment necessary for the development of the inquiring attitude.

(5) Lead the students through a range of logical processes in arriving at a generalization inductively, demonstrating ability to use psychologically sound techniques of reinforcement sequence, support, etc.

(6) Prepare a simple experimental design for a research problem in some aspect of teaching methodology, for example, a comparison of two methods of teaching a given concept.

(7) Demonstrate observable attitudes of professional responsibility in personal behavior.

(8) Answer questions pertaining to legal and financial operations of the schools.

b. Recommendations for Preparing Science Teachers.

(1) Methods Courses.

(a) The student should be provided with many occasions to see good teaching in action by a) observing actual teachers, b) specially designed films, and c) television.

(b) Opportunities should be provided for actually practicing the procedures the trainee will be using later in his teaching. Provision should be made to participate in laboratory-type activities, particularly at the elementary level, so that the trainee has practice in working with the materials the children will use. Emphasis should be on performance.

(c) Practice should be provided in formulating behavioral objectives and planning teaching sequences and activities which will develop concept and process skills. Since the science preparation of the elementary teacher is usually so limited, a study of conceptual themes should be included in the methods course. This should replace the former study of subject matter topics. Practical applications should be included wherever possible.

(d) Some instruction and practice in evaluation procedures should be provided. This should include some principles of test construction as well as instruction in the use of other evaluation procedures, such as classroom and laboratory performance, interpretation of demonstrations, and illustration of how the latter might be used to modify teaching practices.

(e) The student teacher should be made familiar with the availability of the many appropriate resource materials: films, strips, pamphlets, journals, reference books, sources of laboratory materials and supplies, etc. He should also be taught some of the major features of making purchases of scientific materials, such as making out equipment and supply lists for quotations or bids from different supply houses. This will enable him to purchase economically and advantageously, if he should find himself operating later on a limited science budget.

(f) The prospective teacher should be encouraged to use a wide variety of materials and activities in the classroom procedures and be made familiar with local sources of materials, equipment, locations for field trips, etc.

(g) The growing trend toward individualized, continuous-progress instructional packages calls for an emphasis in preservice education on materials and techniques employed in this mode of instruction.

(2) Student Teaching.

(a) This experience should provide the stimulus and opportunity for the student teacher to experiment with, and investigate, a variety of effective ways to teach. It should encourage inventiveness and creativity.

(b) The cooperating teacher in the school should be a master teacher. He should be familiar with the history, philosophy, direction, and expectations of science teaching. He should encourage the student teacher to apply and experiment with procedures learned in his college preparation. In compensation for the additional effort expected of the cooperating teacher, recognition should be provided commensurate with the time required to keep abreast of advances in education and to counsel the student teacher.

(c) The cooperating teacher should be considered as a member of the team, lending support and giving direction to the new teacher when needed. The opportunity for constructive criticism and guidance is unique in the student teaching situation. If the team-teaching concept is established initially, the cooperating teacher can and should continue to participate in the classroom procedures without adversely affecting the relation between student-teacher and students. For instance, the cooperating teacher might at any time demonstrate a discussion or control technique to the student teacher without appearing to criticize the student teacher. The cooperating teacher should not feel that his responsibility is over, when the student teacher "takes over" the class.

(d) Provision should be made for regular seminars in which trainees discuss their problems, report on new techniques, and hear discussions by experienced teachers in the field. Such meetings are vital for the morale and continued enthusiasm of the student teacher.

(e) Student teaching should provide opportunity for experience in teaching students of different abilities and socio-economic backgrounds.

(f) Student teacher unit credit should be realistic in terms of hours of transportation and preparation, as well as classroom time. Effective student teaching experience requires concentration on the work of teaching. Excessive outside work and courses should be avoided.

(g) The college supervisor should be the link and interpreter between the college and school experiences of the student teacher. The load of a college supervisor should be so assigned as to give due consideration to the time and effort required for the satisfactory fulfillment of this important duty.

C. Continuing Education of Teachers of Science

"Continuing education," rather than "inservice education," is used to emphasize the need for continually changing and revitalizing science education to keep it consistent with new knowledge and techniques being generated rapidly by the disciplines of science, psychology, technology, sociology, and other fields, which contribute to the art of teaching science to children and youth. This term also implies that all of the desirable attributes of competent teachers of science cannot be achieved by even the most effective preservice education program.

The effects of recent innovations in high school science education are now being spread to elementary, junior high, and post-high school levels by similar curriculum improvement groups. A second generation of curriculum reform for high school science is well under way. A continuous cycle of change in the K-12 science curriculum seems inevitable.

Assuming that change by self-direction and by providing for divergence promotes more democratic and consistent improvement than change by fiat, it follows that those persons responsible for curriculum improvement at the local level should employ people who are willing to try promising innovations. Administrators should also establish and nourish islands of creativity and support their staffs, when they fail as well as when they succeed.

1. Role of Continuing Education in the Change Strategy.

   When continuing education of school personnel is viewed as an integral and essential component of all stages of a strategy for curriculum improvement, it assumes a much more important role in the administrative planning of a district than is true when inservice education is seen as merely an opportunity for teachers to improve their positions on the salary scale or to pick up a few new ideas and teaching techniques. In 1966 the National Education Association published the results of their research on the inservice education of teachers. This summary emphasized that inservice education could serve many purposes other than subject-matter orientation. If teachers and supervisory personnel are to assume a greater responsibility for the improvement of curriculum and instruction, it is essential that they keep informed on new points of view, new programs, new insights regarding students and how they learn, new improved teaching strategies, in addition to new developments in science.

   Since not all teachers in a large district, especially at the elementary level, can participate to the same extent in all phases of the program, and since each teacher has his own unique strengths and weaknesses, implementation of a carefully planned and well-timed program of continuing education is an essential component of the change strategy of a district.

2. Goals and Objectives for Continuing Education Programs in Science.

   Professional growth activities for teachers and other school personnel are most effective when they include well-conceived goals and objectives, and carefully planned procedures. Evaluation procedures should involve a continuous assessment of the training program for teachers and other personnel. The program should be modified, when necessary, as a result of this feedback for participating personnel. When the continuing education program is concerned with implementing a new course or new teaching strategies, its effectiveness should also be evaluated in terms of desired student-behavior changes.

   What, then, are the goals and objectives of continuing education in the sciences? Most of the continuing education programs for teachers of science should be designed to achieve one or more of the following general goals:

   a. To assist teachers and supervisory personnel in keeping up-to-date with new developments in science, science education, teaching and learning theory, and educational technology.

b. To provide a means for continuous assessment and improvement of the local science curriculum.

c. To improve teaching strategies and techniques by humanizing them and making them more consistent with the nature of science and its modes of inquiry, with the goals and needs of society, and with the development levels of students and the ways they learn.

d. To provide opportunities for school and district personnel to exchange ideas with each other and with members of the community and outside consultants, which result in new insights, attitudes, and coordination of effort. Consequently, the individual teacher, the school, and the community all gain from this program.

Aside from these general goals, there may be particular goals arising from a district's needs at a particular time. For example, at one point in the change cycle, the emphasis may be on informing staff members concerning new trends and practices. At other times, programs may be designed for pilot teachers who are testing and demonstrating new programs, strategies, or materials. Once an innovation has been adopted and is ready for general dissemination to all teachers in a department or district, another continuing education program may be set up precisely for the purpose of disseminating this information and, if need be, of training all personnel involved.

3. Responsibility for Planning and Conducting a Program for Continuing Education.

The professional growth needs of all personnel involved in science education are so vast in scope that total responsibility for continuing education cannot be placed on any one individual or group. Traditionally, the individual teacher has been expected to assume responsibility for his own professional growth. In view of the extensive and rapid changes that have taken place in education, it is now necessary to provide experiences, time, and money, which will permit and encourage the individual teacher to pursue a continuing professional improvement plan.

The National Commission on Teacher Education and Professional Standards of the National Education Association makes the following statement in this regard:

> "The responsibility for inservice education is mutual. School systems should make time, resources, and growth situations available; the professional teacher should contribute resources, time, effort, and enthusiasm."[4]

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[4] National Education Association Commission on Teacher Education and Professional Standards, A Statment of Policy, 1956, Page 12.

a. District-Sponsored Programs.

In most instances the school district is the best agent to serve as the "hub" for the planning of a comprehensive professional growth program that will have immediate and effective impact on classroom instruction. This is not intended to minimize the roles of individual teachers and other agencies such as individual schools, counties, ESEA Title III Centers, State Department of Education, professional societies, National Science Foundation, etc., which must continue to contribute. Such an extensive list merely serves to emphasize the need for more complete cooperation on the part of all who contribute to professional development of science education.

Logically, the efforts of the local school district to improve science education at all grade levels will focus on factors such as improvement of teachers' competencies, improvement of the existing science programs, and implementation and evaluation of promising innovations. The local school district has the necessary communications system to provide information on specific professional growth needs which are closely related to classroom instructional problems and to the local curricula. The communications within a district operate quickly enough to permit identification of needs in time to take the necessary action. Individual schools are normally too small a unit to develop a comprehensive continuing education program. Colleges must, of necessity, plan programs which will serve an entire region, and college personnel usually are not a part of the immediate communications system involving local science teachers. Hence, the immediate responsibility rests largely with the local district, which seems to be best qualified to meet this responsibility. How, then, are the local school districts to proceed to fulfill this function? Several guidelines and suggestions are given below. These were derived from the experience of several districts and counties of California, and from current literature on the topic.

GUIDELINES FOR DISTRICT-SPONSORED PROGRAMS

(1) Identify or develop effective channels of communication.

Set up effective channels of communication within the district and between or among other districts, the county office, and nearby colleges and universities, which are involved in the program. It is important to involve administrators, supervisory and resource personnel, and school science department chairmen in developing and maintaining the channels of communication with the teachers.

(2) Determine continuing education needs.

Survey the needs for professional growth on a continuous basis, using written survey techniques, direct contacts with teachers, requests from curriculum development committees, ideas from department chairmen meetings, suggestions from supervisory and resource personnel, and new developments reported at conferences and in professional literature and research reports.

(3) Make plans to meet immediate needs.

A cooperatively developed list of district professional-growth needs usually includes a wide variety of specific needs and several long-term needs. Teachers tend to express specific needs, resulting from their day-to-day problems. Curriculum specialists, on the other hand, are more often concerned with basic philosophical or methodological changes which may require several years to develop and implement. While a steering committee is considering and developing plans for long-term programs, the enthusiasm and cooperative attitude of the other participating personnel can be maintained by the organization and implementation of short-term programs, designed to promote immediate improvements in the science program. Typical short-term needs might include such as the following: a) how to ask the kind of questions and make assignments which will elicit creative behavior in students; b) how to develop specific behavioral objectives for current lesson sequences; c) how to prepare transparencies for overhead projectors; d) how to organize a class for small-group investigations; e) to inform teachers about new developments in solid-state physics, or similar developments; f) how to provide for individualizing instruction. Some special needs may arise unexpectedly, perhaps as a result of ideas picked up at a conference or a summer institute, or perhaps as a result of a gift of unusual equipment with which the teachers are not familiar. District plans should be flexible enough to meet these needs without delay.

(4) Develop programs to service long-range plans.

Begin to "plant the seeds" today for programs which will be, or should be, in operation in the future. This not only prepares the teaching staff for changes to come, but also paves the way for extensive educational gains resulting from experimenting with new or different programs or materials. Examples of the latter include such as are produced by elementary school science programs, ESS of ESI, Minnemast, SCIS, AAAS, and other various national programs for junior and senior high schools. Programs which involve materials and teaching strategies which are radically different, in theory and operation, from those currently in use often require meetings and practice sessions for an extended period of time. Such programs should be budgeted and scheduled well in advance of the time they are to be implemented.

(5) Capitalize on resources within the district.

Some of the most effective programs are presented by teachers and other staff members from the local district. This type of program usually results in the practical, day-to-day classroom application of ideas which meet with approval from fellow teachers. It also stimulates creativity, encourages local personnel to try new and different ideas, techniques, and materials. Key teachers and other district personnel, who serve as pilot teachers for new programs, also provide for the district a local unit of teacher consultants who assist other teachers in implementing a new program.

(6) Cooperate with other agencies sponsoring continuing programs for science teachers, which are consistent with the goals of the district.

(7) Utilize local scientists, facilities, and natural resources.

Involve personnel from local industry and research organizations in professional-growth opportunities for teachers. Make it possible for science teachers to meet local authorities personally, to visit their laboratories and shops, such as the zoo, aerospace research and development firms, marine laboratories, outdoor education facilities, etc.

(8) Make continuing education programs attractive to teachers.

Provide release-time or paid summer-time for those involved in extensive training or curriculum revision programs. Traditionally, district salary schedules allowed only "hurdle" credit for professional-growth activities other than approved college courses offered for credit. In recent years, a growing number of districts have found that a thirty-hour or forty-five-hour institute series or summer workshop designed to meet a specific district need can result in as great, or even greater, benefit to both the district and the individual than a random selection of credit courses. These districts grant salary increment credit for such professional-growth programs, provided that they are first approved by the administration and board, that the district controls (or at least approves) the content and consultants, and that participants attend regularly and complete assignments and other required work.

(9) Develop a district budget for professional-growth and curriculum-development activities.

Many continuing education activities can be offered without special budget appropriations. However, a comprehensive program will often involve out-of-district personnel, special materials, etc., which will necessitate special financing. A budget for inservice education should include such items as: equipment and supplies, special out-of-district consultants, instructors, released time for teachers, administrative coordination, out-of-district travel expenses, and development or purchase of special training materials. It is recommended that one per cent to two percent of a district budget be set aside for research and development, which includes professional-growth activities.

(10) Utilize all media in providing continuing education.

Information materials of all sorts, such as newsletters, progress reports, bulletins, instructional suggestions, etc., should be supplied regularly to teachers. Convenience, clarity, and usefulness in implementing the program in the classroom should be the main concern in producing such materials.

Educational television appears to have considerable potential as an instructional device for continuing education programs. Attention should be given to the use of currently available materials. New science instructional programs can be developed with related ITV tapes for teachers. Portable video tape equipment for recording demonstrations and classroom activities is a useful adjunct to a professional-growth program. Cooperative efforts should be initiated with regional and state agencies in providing needed ITV programs.

(11) The effectiveness of each continuing education program should be evaluated in terms of desired changes in the behavior of students, as well as in terms of teacher growth.

(12) A wide choice of alternative activities should be provided.

Such a variety would make possible a truly individualized continuing education program, based upon a diagnosis of what an individual teacher needs. Some teachers may need help in improving their teaching strategies, even though they are highly competent in their science subject matter. Others may be skilled in inquiry processes but have little understanding of the fundamental concepts and principles of a given subject area in science. The availability of sound-slide projectors, film loop projectors, and other equipment, which may be programmed for individualized instruction, makes such continuing education possible.

b. County or Regionally Sponsored Programs

Although adoption and dissemination of innovative programs is primarily a district responsibility, and the district is the logical "hub" for operating continuing education programs, for the reasons mentioned in the previous section, nevertheless, current practice indicates that some of the most comprehensive and effective continuing education programs are planned and conducted on a regional, rather than on a district basis. The goals and objectives of county and regionally sponsored programs are similar to those stated for district sponsored programs. However, there are certain needs which are best met by interdistrict sponsorship, depending upon such conditions and assumptions as are listed below:

(1) Regional cooperation is needed to marshal the necessary resources and to make most effective use of these resources, when the districts are not large enough or wealthy enough to do so.

(2) District leaders, regardless of the size of the district, may become so involved in growth and financial problems that they fail to keep up with new ideas and practices. In such cases, interdistrict sponsorship encourages interchange of ideas and practices, opens up new channels of communication, and increases the changes for an innovation to spread and flourish.

(3) A cluster of neighboring districts, having a common problem, may wish to implement the same program.

(4) A regional professional society, or nonschool agency, which covers several districts may become engaged in a project which involves teachers from these several districts.

(5) Regionally sponsored projects are desirable when a new program or innovative practice, requiring outside consultant help, is being introduced to only a few key personnel in each of a number of districts in a county or region, on a pilot basis, prior to general dissemination. Such projects should have a built-in procedure for second generation dissemination. Those who have been selected as "pilots" should be expected to teach others their newly acquired skills.

(6) Continuing education is a responsibility shared by many, including the individual, the districts, county and intercounty agencies, regional professional societies, regional associations of county superintendents, state departments of education, commercial producers of instructional programs and materials, and colleges and universities. Professional-growth programs sponsored by colleges and universities should aim primarily at renewal and extension of teacher skills and innovation, rather than remedial instruction.

GUIDELINES FOR COUNTY OR REGIONALLY SPONSORED PROGRAMS

(a) The goals and objectives should be clearly stated.

(b) A cooperative attitude among participating agencies is essential.

(c) Interagency administrative and financial arrangements should be developed in advance, be approved by all participating agencies, and modified only by mutual consent.

(d) In most instances new communication channels will have to be developed and used. Poor communication is a major cause of failure of cooperative programs.

(e) Policy decisions should be made in a democratic manner. One individual or agency should not attempt to, or be allowed to, dominate the decision making process.

(f) In general, the guidelines listed for district programs also apply to regionally sponsored programs.

4. Relative Effectiveness of Different Types of Continuing Education Programs.

Not all types of continuing education programs are equally effective. A brief review of some of the types will illustrate this.

a. Occasionally scheduled events held during out-of-school time, or on a released-time basis during school hours, for special purposes such as to hear outstanding speakers, observe demonstration lessons by master science teachers, become acquainted with new materials, equipment, discuss special needs and so forth, may be effective first steps in motivating improvement of instruction in science. However, isolated events of this type have little long-term effect without some sort of follow-up.

b. A carefully planned institute series involving a considerable amount of time with qualified leaders to accomplish certain specific objectives is an effective means if the activities require active involvement of participants and close relation to their goals.

c. On-the-job experience in the classroom is one of the most effective inservice training types, since it involves the teacher in trial use and evaluation of new materials and methods in the development of science curriculum. Here the understanding, encouragement, and support of the school administrator can play a key role.

d. Formal courses conducted by colleges and universities for updating and enriching the competencies of science teachers provide for the depth of training needed in special areas. Participation in these should be encouraged.

e. Research participation in college, university, or industrial laboratories, or in public, private, and governmental agencies which provide for field work in scientific disciplines, provide excellent opportunities for developing the skills, attitudes, and approaches needed in teaching science.

CHAPTER V

RECOMMENDATIONS

(To be added)

CHAPTER VI

BIBLIOGRAPHY

(To be added)

CHAPTER VII

INTRODUCTION TO GLOSSARY

In this glossary we have concerned ourselves mostly with defining scientific and educational terms in the light of the way in which they are used in this document. For some terms, in an effort to clarify, we have included several definitions. The reader may use whichever one is most meaningful.

Something should be said also about the use of terms that are used differently by the scientist and the psychologist. An example is the use of the word "concept." To the psychologist, the term means the first organization of percepts. To the scientist, this first process of organization is a "construct," and the word "concept" refers to a much more sophisticated level of intellectual process. Throughout this report an effort has been made to use terms as a scientist would use them. This follows from our belief that terminology should be consistent with the discipline. Thus, as another example, the reader will find the word "theory" used as a scientist would use it, and not as it might appear in an educational context. It is not, for example, a synonym for a child's hunch, guess, or model.

We are aware that a glossary of this kind will not be entirely adequate. In spite of its limitations we hope that it will provide some clarification for the reader. It has already proved to be of considerable benefit to the writers, for it caused much "soul-searching" in order to arrive at definitions which we could, in general, accept.

GLOSSARY

CHARACTERISTIC - a distinguishing feature or attribute of an object or event.

CONGNITIVE - having to do with knowing and coming to know.

Skills - skills by which we enhance our ability to know.

Style - the unique or peculiar method of processing information or ideas by an individual or group.

CONCEPT - an abstraction or generalization inferred by an individual from many percepts of events or objects with certain qualities in common.
- refers to thoughts, ideas, or notions.

CONCEPTION - a notion, idea, or logical construct that conceived or brought into being.
- implies a focus on its being conceived or coming into being which gives it a different connotation than concept.

CONCEPTUAL MODEL - a representation of a concept.

CONCEPTUAL THEME - major generalizations or generalization sets.
- involved or complex statements which combine concepts from a broad field of knowledge (same as conceptual scheme).

CONSTRUCT - in science, the lowest level of mental synthesis. The word "concept" is often used synonymously, but in science it represents a higher level.

DATA (scientific) - raw material, such as observations, that has been processed in some way.

DIAGNOSIS - (of behavior) recognizing and identifying certain symptoms of overt behavior which indicate the status of, placement on, or deviation of the learner from some standard or norm.

EDUCATIONAL GOALS - long range outcomes of education stated in general terms.

EXPERIMENTS - the rational use of observable operations employed to verify an hypothesis.

GENERALIZATIONS - a relationship between one or more concepts. Example: "Heat makes metal expand" is generalized from the concepts of heat, metal, and expansion.

Basic - those generalizations that are of a simpler or more fundamental nature.

Major - conceptual themes.

HYPOTHESIS - hunches, beliefs, assumptions, or notions.

IMPLICATIONS - logical propositions that are derived from a model and are valid if the model is valid.

INFERENCE - an assumption based upon data, experience, or information.

INVESTIGATION - an examination: of properties or functions of objects; into causes and effects of events; or into interrelationships of objects and/or events.

LAWS OF NATURE - generalized statements of natural processes.

LEARNING THEORY - a theoretical construct or model which explains how or why a certain thing happens.

MENTAL MODEL - an idea that for the moment explains how or why a certain thing happens.

METHOD - the general logical procedure that is followed by a scientist in his work.

MODES OF INQUIRY - methods used in searching for truth, seeking information or knowledge.

NATURAL LAWS - see laws of nature.

OBJECTIVE - something toward which an effort is directed.

Behavioral - aims of instruction stated as specific behavior of students anticipated as a result of learning opportunities.

Operational - (in education) - descriptions of behavior that students may achieve as a result of structured learning opportunities.

Terminal - aims of education stated as the end product of learning opportunities.

ORGANIZERS - data, concepts, systems, past experiences. Ideas which a person holds and brings to bear in the explanation of phenomena.

PARADIGMS - examples or patterns.

PERCEPTS - an impression of an object or event gained by the use of the senses.

PREDICTION - when it is said with a degree of certainty that: If this is done, then this will happen, we have a prediction.

PRINCIPLE - statement of fundamental or general truth so well established as to be above ordinary question.

PROCESS - skill group, for example, observing is a process using the skills of seeing, reorienting, relating visual perceptions, etc.

Cognitive - see cognitive skills.
- according to Bloom, the cognitive processes are: recall, comprehension analysis, synthesis, application evaluation.

Intellectual - mental processes.

Mental - mental refers to the total emotional and intellectual response of an organism to its environment.
- includes the operations of thinking and attending, that is, analyzing, inquiring, explaining, predicting, accepting, rejecting, hypothesizing, and verifying.

Rational - (of inquiry) - the variety of ways a person has available to him for manipulating and transforming information and ideas logically.

Scientific - the mental and overt operations utilized by scientists. These include: observing, communicating, comparing, organizing, relating, inferring, and applying (technology).

PROPERTIES - an attribute or characteristic of an object, often one which involves scientists in the attempt to explain natural phenomena.

SKILLS - (manipulative) skill in constructing and using laboratory apparatus, recording and organizing data, graphing, etc.

STRAND - a thread that weaves through a subject. Strands are used to give a continuity to the curriculum.

STRUCTURE (of a discipline) - consists of at least four elements:
1. A body of knowledge,
2. A method of inquiry,
3. A mode of behavior, and
4. Some unanswered questions.

TECHNIQUES (teaching) - the specific actions of the teacher within a strategy.
- the overt tactics which a teacher employs.

THEORIES - tentative statements which have the power to explain the natural world and which can be subject to experimental verification or falsification.
- a fluid level of inquiry that attempts to tie laws into a higher level of understanding. For example, Newton's laws of motion are tied together with other special laws of motion by Einstein's theory of relativity.

APPENDIX A

CONCEPTUAL THEMES

Facts do not constitute science. Science exists only when relationships are discovered. Science is an invention of man which enables him to order information and to conduct systematic search. From this scientific enterprise, sets of related ideas (concepts) and investigative processes have emerged. The concepts and processes provide the structure on which a science curriculum is built.

The learning of related sets of concepts, or conceptual themes, should be the basis for the development of content in science because: 1) It is the very nature of science to be a continual search for greater and greater generalizations; 2) Conceptual themes provide a foundation for the understanding of how certain facts are related; 3) Conceptual themes provide education for the future because they offer a perspective by means of which future discoveries may be correlated and understood.

THEME A: Events in nature occur in a predictable way, understandable in terms of a cause and effect relationship; natural laws are universal and demonstrable throughout time and space.

This first concept is an overall summation of the twelve conceptual themes, and their elaborations are specific examples of this primary general theme. In order to evaluate and substantiate the initial theme, it is restated in the following form:

1. Events in nature are the result of a cause and effect relationship.
2. Knowledge of cause and effect allows prediction of events.
3. The findings of cause and effect relationships are universally applicable.
4. Randomness and uncertainty are also predictable from cause and effect relationships.

Events in Nature Are the Result of a Cause and Effect Relationship

The laws and theories of nature--as they apply to motion, energy, change, conservation, atomic structure--are simplifying generalizations in which a cause and effect are related. They are based on experience and verified by experiment. To state a thesis which is not subject to experimental test is to state no thesis at all. The primacy of the quantitative experiment is the dominant factor.

Knowledge of Cause and Effect Allows for Prediction of Events

Knowledge of the motion of the earth and moon allows predictions of the sunrise and sunset and of the time and magnitude of tides. Knowledge of chemical bonding allows prediction of the heat that will be liberated when acid is added to alkali. The validity of a prediction based upon cause and effect relationships is determined by the reproducibility of experimental results, which have been obtained after many experiments have been performed, using a variety of experimental approaches.

The Findings of Cause and Effect Relationships Are Universally Applicable

The laws of motion apply to planets as well as to electrons; to birds as well as to airplanes. The laws of chemical equilibrium apply to oceans as well as to humans. Matter of the same composition has the same properties, regardless of its origin. Thus, ethyl alcohol has the same characteristics whether it comes from grapes or from a laboratory preparation.

Randomness and Uncertainty Are Also Predictable From Cause and Effect Relationships

Uncertainty in prediction can frequently be overcome by making use of the laws of probability. These laws provide a true description, on a statistical basis, depending, of course, upon the system and our knowledge of it. For example, we can predict the fraction of atoms which will disintegrate in a given mass of radioactive atoms, but we cannot predict when any one atom will disintegrate. The same is true of predictions regarding the energy in molecules; we can predict what fraction of them will have a particular energy, but we cannot predict the energy locked in any one of them. Again, in the field of genetics, it is predictable what proportion of children will be boys, but the sex of a particular child is not predictable.

Inconsistencies, that is, predictions which are not verifiable by experiment, lead to reexamination of scientific hypotheses, and to changes and improvements in them, in an effort to account for all observations. This way of proceeding represents a break with superstition, and with the idea that natural phenomena cannot be explained by the laws of nature. Even if the cause and effect relationships are not understood immediately, persistent pursuit for answers will eventually lead to understanding as our knowledge increases.

Prediction of scientific phenomena is, at one and the same time, a statement of faith in a natural law and of hope in the fertility of its applications. Although a prediction may result from a century of experience, it must still meet the requirement of experimental verification before it can be accepted as valid. Proof means demonstrable validity in every test, and not mere acceptance by concensus of opinion or by vote.

THEME B: Frames of reference for size, position, time, and motion in space are relative, not absolute.

This conceptual theme deals with measurable attributes of things and events. It can be developed in two parts:

1. Objects are weighed and measured to determine magnitudes. The position of an object is determined by measuring its distance and direction from other objects, or from fixed basepoints. Events in time are measured by means of clocks marking off intervals from a reference point in time. The motion of an object can be characterized in terms of its changes in position with time.

   All these measurements are done with reference to appropriate scales: Weight may refer to pounds or grams or kilotons; measurements can be in inches, or meters, or light-years. The latter measurements also imply direction and distance from other objects or from fixed basepoints. Indirect measurements, such as the measuring of a child's shadow to deduce the sun's position, are used to measure the relative positions of objects we cannot reach. Clocks measure time in seconds, minutes and hours--Calendars indicate days, years and centuries. Living things have biological clocks set, for example, to light-and-dark daily schedules and to the temperature of seasons. Motion in space is a combination measurement--a change in position with time, the measurements just mentioned. The greater the distance traveled from a fixed point in a given time, the faster the motion; the slower the motion, the longer the time taken to go a given distance. The most difficult quantitative concepts are those which fall well beyond the level of intellectual comprehension: The numbers of atoms, stars, or insect populations--the measure of atomic or astronomical dimensions.

2. The frames of reference for these measurements seem rigid and constant--a pound is a standard unit of weight, valuable because of its constant dependability. Transfer the pound to an environment outside the earth's gravitational effect, however, and this standard unit of weight loses its rigid, constant, earth-bound value. "Weight" values, when measured by earth standards on the moon, on Jupiter, or in an orbiting space capsule would be less, more, or even nothing. Consider an astronaut's measure of a day as rapid revolutions spin him through several "day-night" experiences during one earth-day. Scales can be more definitive if the frame of reference is expressed, that is, an earth-day, an earth-pound.

   The situation becomes more abstruse when motion in space is considered. The velocity of a vehicle speeding towards Mars, such as Mariner II, has a rate of motion relative to Earth, another which is relative to Mars, and another relative to the Sun. The Earth, Mars, Sun and Mariner II each travel at different velocities and in different directions.

The principles of relativity can be stated simply as specific problems of relative positions. For example, on the playground the movements of children may be observed relative to the fixed position of the observer or his movements. The complexities of Einstein's General Theory of Relativity need not be involved. The choice of reference frame within which various physical or biological properties are considered produces the level of complexity. Measurement within relative frames of reference challenges the student to interpret observations by quantitative means. The numbers derived from measurement data can be processed with the developing tools of arithmetic, algebra, geometry and calculus--an increasingly compelling and efficient logic. Thus the conceptual theme which considers the role of an observer relative to his experimental environment provides a broad bridge between science and mathematics, over which the two disciplines can develop in concord and to reciprocal advantage. For science, most of the "Elementary processes" relate to the measurements subsumed in this concept. For mathematics, the "strands" take substance in the definition and application of this conceptual theme.

THEME C: Matter is composed of particles which are in constant motion.

Different kinds of matter fall within certain varieties and patterns which are basically classified by the particulate nature of the substance and the energetic movements of the particles. The following examples explain the particulate nature of matter, which is one of the best models that scientists have to explain observations of natural phenomena. This model includes the concept that the particles are in constant motion.

The major building blocks of matter are atoms which may join together to form a molecule. For example, similar atoms join, as in the case of molecular hydrogen (H_2) or sulfur (S_8), or different atoms may bond to form molecules as in the case of water (H_2O), carbonic acid (H_2CO_3) or sugar ($C_{12}H_{22}O_{11}$). The molecules may be grouped to form matter whose physical states can be explained in terms of the spatial relations and energy. In the solid state, the molecules are tightly bound and vibrate about fixed points. When energy in the form of heat is applied to the solid state molecules, they vibrate more energetically, but vibrate about or around the same relative positions without leaving the environment of their adjacent molecules. The average molecular pattern or structure remains the same until the heat energy is sufficient to change the substance from a solid to a liquid. In the liquid state, the molecules are less tightly bound, and are free to roll around and over each other. If still more heat energy is applied to the substance, the liquid changes into a gas. In the gaseous state, the molecules have sufficient energy of motion to overcome their mutual attraction and, consequently, are free to move in a completely random manner.

The process just described can be reversed when the heat energy is removed so that the gas can be returned to a liquid or solid by the process of cooling. The changes which have been discussed are purely changes in the physical states of particulate matter, for the molecular structure of matter has undergone no basic change. Water is still H_2O whether it is in the solid state (ice), liquid state, or gaseous state (steam).

Three kinds of motion are associated with the molecules of a substance. In translational motion the molecule moves from place to place; in rotational motion the molecule rotates about its center of mass; and in vibrational motion the atoms of which the molecule is composed move alternately toward and away from the center of mass.

Though the atom is called the "basic building block of matter," it is itself made up of smaller parts, subatomic particles, such as protons, electrons and neutrons. In the atomic model, the electron is moving rapidly in the vicinity of a nucleus and particles within the atomic nucleus possess considerable kinetic energy. Subatomic particles have angular momentum, as if spinning about an axis.

In addition to electrons, protons, and neutrons, more than thirty subatomic particles have been identified, although their role and interrelationships are not yet completely known. It is expected that present ideas about the nature of matter will change, as new experiments lead to new knowledge.

A cell represents the smallest known structure that can be fully alive. The cell is composed of complexes of compounds (called organelles) which are composed of molecules formed by the joining together of atoms. In a cell, new substances enter continuously, wastes and manufactured products leave continuously, and substances in the interior of the cell are continuously transformed chemically, and redistributed physically. Thus the constituents of living matter are in constant motion. Detection of the odors of perfume, mothballs, and gases at a distance from their sources are simple examples which give evidence of motion of matter. Finely divided particles suspended in a liquid under a microscope are observed to dance back and forth with irregular motion produced by molecular bombardment (Brownian movement). Transpiration in plants, growth of molds, diffusion across permeable membranes, the motion of ions, are examples of motion of particles. An understanding of the particulate nature of matter is essential for explanations of the more complex phenomena of natural events.

THEME D: Energy exists in a variety of convertible forms.

Energy and its conversion is a common strand that runs through all sciences, from physics to biology, from geology to cosmology. Man's rise from being his own beast of burden to his development of modern technology has been in direct proportion to his ability to find and convert energy to replace muscle power. A direct measure of a nation's progress and material well-being is the average amount of energy consumed per citizen per year. Man's ultimate downfall may be his pollution of the atmosphere by his conversion of energy from fossil fuels or by the catastrophic release of the energy locked within the nucleus.

The origin of most energy-forms on earth can be traced directly or indirectly to radiant energy from the sun. This radiant energy can be reflected, scattered, absorbed, transmitted or refracted, and results in man being a creature who lives in an ocean of energy. **The earth inherits only one-half billion of the sum's total** output of energy, yet much more or much less would destroy all life as we now know it. This small fraction of the sun's energy resides on earth temporarily before it continues outward in space, changed only in direction and spectral distribution. One by one, the multitide of potential and kinetic energy forms that man requires can be traced back to their thermonuclear birth on the sun.

The law of conservation of energy rests on many observations that energy cannot be created or destroyed, but only converted from one form to another. With reservations concerning the interaction of matter and energy, the total energy in a system is constant. There can be no perpetual motion or any device whose energy output exceeds its energy input. Energy can only be studied (indeed can only be defined) by its effect on matter, and all changes in matter involve a capture or release of energy.

The "strand" of energy conversion underlies every major scientific discipline. The physicist sees energy as the capacity to do work, kinetic energy as the energy of a moving object, and the work done as a measure of the energy transferred. A swinging pendulum becomes a transformation from potential to kinetic energy and vice versa. Sound becomes a transfer of momentum through a medium, and molecular motion becomes a determiner of heat and state of matter.

Electrical energy is the result of electrons or ions in motion, and electromagnetic energy is transmitted by wave motion. The chemist observes that the energy transfer between molecules results whenever they collide. Potential energy of atoms and molecules is lowered when electrical forces bind them together and is raised when these bonds are broken. The nuclear scientist presently converts some of the energy of the atomic nucleus to heat through nuclear fission and fusion, and is seeking more direct and more efficient conversion. The meteorologist and oceanographer consider their domain as part of a heat engine driven by solar energy, and modified by factors such as the earth's rotations. The astronomer gathers electromagnetic energy from the far reaches of the cosmos. The geologist observes the energetic forces of erosion shaping our earth, and speculates upon radioactivity as the probable source of the earth's central heating system. The biologist understands that all changes in living organisms from simple cells to complex man involve a flow of energy to and from the environment. The energy transfer of the photosynthetic process is the basic source of energy for all living things. Photosynthesis, in turn, is based mainly on the conversion of the thin band of radiant energy, which man sees as light. The solar energy captured by chlorophyll enters living systems and is used with amazing efficiency to organize matter. Only bit by bit does it emerge as heat energy to the non-living world.

Living things are receivers, distributors and organizers of energy in space and time. All of man's activities depend on his ability to obtain and make efficient use of energy resources. All motion and all change involve energy transformations. Falling water, a bouncing ball, metabolism of food, a penetrating gamma ray, a 100-foot geyser, a spinning radiometer, a plasma engine, and a comet are all explainable in terms of energy conversions. The problems of harnessing geothermal forces, confining nuclear fusion by magnetohydrodynamics, and setting foot on the moon, require energy conversions. Meeting the energy needs of the world's expanding population fundamentally means finding more energy sources and more efficient conversion devices.

THEME E: Matter and energy are manifestations of a single entity: Their sum in a closed system is constant.

In our ordinary day-to-day experiences, the laws of conservation of matter and conservation of energy seem to be universally applicable. However, investigations of certain subatomic and cosmic phenomena show that matter can be converted into energy and vice versa. In such changes the relationship is expressed by Einstein's famous equation $E = mc^2$. Two important characteristics of this relationship are: first, that the amount of energy (E) appearing or disappearing is dependent upon (or proportional to) the amount of matter (m) which is destroyed or created; and second, that since c (the proportionality constant) is a large number, a small amount of mass is equivalent to a very large amount of energy. These points may be illustrated by examples such as the following:

1. In ordinary chemical reactions--decomposition of limestone by hydrochloric acid for example--there is no measurable difference between total mass of reactants and total mass of products. Also, quantitative measurements show that energy liberated is not "created," but is simply the result of changing chemical energy stored in the atoms and molecules into some other form of energy such as heat energy. On the other hand, during decay of radioactive elements such as Radium, or when Uranium 235 decomposes into lighter elements in the explosion of an atom bomb, there does occur a loss of matter and the creation of energy. Furthermore, the energy gain is proportional to the amount of matter lost, as called for by the equation $E = mc^2$.

2. Similarly in the burning of a candle or any common fuel, both matter and energy are conserved. But in the fusion reactions which take place in the sun and in the hydrogen bomb, matter is destroyed and energy is created. Again the relationship is $E = mc^2$, and a very large amount of energy results from a small loss of matter.

3. The amount of matter in a stationary object is not changed measurably by putting it in a fast moving airplane. None of the energy gained when speed is increased is converted into matter. However, man-made devices make it possible to accelerate electrons and some other subatomic particles to very high velocities approaching the speed of light. Under such extreme conditions some of the kinetic energy of the fast electron is converted into matter. At 18,600 miles per second (one tenth the speed of light) the increase in mass is only half of one per cent, but at 90% of the speed of light, the particle's mass is more than doubled.

4. When two automobiles collide their kinetic energy is transformed into heat energy, but the total mass does not change, that is there is no measurable conversion of energy into matter. But when very high speed protons collide, their loss of energy results in the creation of matter in the form of particles which did not exist before the collision. The most common result is the formation of pi mesons, but occasionally anti protons may be formed.

5. When a piece of flint is struck with a piece of steel, sparks result. Kinetic energy of the moving steel is changed to heat and light energy, but matter is not converted into energy, and there is no measurable change in total mass of the system. In subatomic systems, however, it is possible to have collisions or combinations resulting in complete annihilation of matter and the consequent creation of energy. For example, if an electron and a positron come in contact, they both disappear and a photon of radiant energy is created. A similar phenomenon occurs when a proton and an anti proton combine. In fact, antiparticles corresponding to most of the know subatomic particles are believed to exist. The energy of the photons so created is dependent upon the energy and masses of the disappearing particles.

Throughout the universe matter is constantly being transformed into energy, and simultaneously matter is being created from energy. A currently popular belief is that the two processes are in balance. Whether or not such a state of equilibrium has been attained, all available evidence confirms the validity of the conclusion that the sum of matter and energy remains constant.

THEME F: Through classification systems scientists bring order and unity to apparently dissimilar and diverse natural phenomena.

Ancient Greek philosophers asserted that from *Chaos*, a state of complete dissimilarity and diversity, of utter chance confusion and lawlessness, evolved *Cosmos*, the perfectly arranged and ordered universe. This strong belief in an ordered (or orderable) universe has persisted in Western thought and today serves as a basic foundation for modern empirical sciences.

Through observation and analysis, scientists sort out and identify dissimilar and diverse characteristics or properties of natural phenomena which may lead to interpretation and prediction.

They search among these characteristics or properties for generalizations or principles which might tend to serve as unifying themes or principles upon which classification systems or taxonomies can be developed.

Apparently-diverse phenomena have been ordered or classified upon the principle of degree of simplicity or complexity of organization in natural systems. The taxonomy of Plant and Animal Kingdoms, the periodic tables of elements, and the electromagnetic spectrum are examples of classification systems based upon underlying principles or unifying themes. Varieties and patterns in rocks, based upon their inferred origins, give rise to distinctive organization into igneous, metamorphic, and sedimentary characteristics.

Recognition of diversity in the universe, accompanied by attempts to relate these differences, is the very process by which order is brought forth. Differences in the characteristics of stars ranging from spectral contrasts to dissimilarities in radio-wave emissions allow the astronomer to suggest remarkable groupings, from which theories of stellar evolution emerge.

In any classification devised to bring order to the universe there must be an awareness that the system is, after all, made by man and for man. The human intellect has superimposed upon nature a system in order to better understand the universe. It is not surprising, therefore, that certain objects do not fit man's classification systems. Man is, in a very real sense, limited in his understandings and descriptions of natural phenomena to, and by, his mental processes and patterns. He is also limited (in part at least) by the modes by which he acquires knowledge.

THEME F-1: Matter is organized into units which can be classified into organizational levels.

Structure within the natural order is observed in classifications from the smallest subatomic particles to the organization of matter within hugh galactic masses. Basic units of matter, small or large, are found in every organizational level in the physical and biological structures of the natural order. Scientists attempt to bring order to the world they investigate by grouping and classifying matter according to the properties it exhibits.

The utility of any classification system depends entirely upon the properties selected for measurement. The capabilities of man in his realm prevent him from making direct observations of very large and, particularly, of very small forms of matter. For these he is forced to rely upon models of his own devising; depending upon his ingenuity in developing them, these models will be successful in accounting for such properties as are amenable to measurement. Classification systems based upon the degree of complexity of a sample of matter with respect to some fundamental (and perhaps modular) unit are to be found in all of the natural sciences. Selection of the basic unit in turn varies with the particular field of inquiry. The cell, which represents an elemental unit to the biologist, is a highly complex system in the view of the chemist; similarly, entities that are conveniently considered fundamental with respect to chemistry are possessed of great intricacy from the standpoint of the nuclear physicist.

Within each organizational level the necessity exists for further distinction between forms of matter that resemble one another in terms of complexity, but differ with respect to function.

Forms of matter that cannot be altered into simpler entitles by chemical means are called elements. A highly successful model conceives of atoms as the smallest subdivisions that retain the properties of an element. In terms of this atomic model, the properties of a particular type of element are determined by the number and arrangement of electrons about a central nucleus. Although a completely satisfactory model has yet to be proposed, there is every indication that the arrangement of protons and neutrons within the nucleus is also orderly, and that indeed, each of these particles may be composed of even more fundamental forms of matter.

Combinations of elements give rise to more complex forms of matter, called molecules. Molecular constitution ranges from the very simple, such as hydrogen gas, to the highly complex, as typified by a protein.

Aggregates comprising different types of molecules result in even greater complexity; a particular and important class of combinations is matter that possesses the ability to reproduce itself at the expense of its surroundings.

Even as the atom represents a fundamental organizational unit for the chemist, the cell fulfills much the same function for the biologist. An analogous increase in complexity occurs as aggregations of cells are considered, ranging from the relatively simple (tissue) to the highly complex (living organisms). As with the atom, the cell itself is composed of several types of matter, each of which possesses a unique complexity.

THEME F-2: Living things are highly organized systems of matter and energy.

The interactions of life within various systems may be characterized by an immense hierarchy or organization ranging from the minute atomic and molecular interactions to the vastness of the biosphere.

The biosphere is the layer of living matter spanning the earth from within its crust to its upper atmosphere. All the plants and animals of the world are inhabitants of the biosphere. All organisms are in constant interaction with each other and with their environment. For this reason, the biosphere may be viewed as an integrated whole. For other purposes of study the biosphere may be recognized to have smaller subsystems within it. These smaller subsystems are called ecosystems.

The ecosystem has smaller units which are known as communities. A community is a web of plants and animals which has adapted to a particular environment. Thus a community might be life in a pond, in a vacant lot, or in an intestine.

The individual specifically related animals or plants in a community constitute a population, such as a population of mice, tapeworms, ferns, or amoeba. Regardless of the level of organization, an interaction of matter and energy must be maintained, or the components will become unbalanced and thus the system will degrade.

Each single individual within a population is considered an organism. Although this is the level commonly associated with life, it would be a mistake to presume that a single organism can exist in isolation. Each organism is dependent on other forms of matter for a continuity of energy.

Organisms are interacting units within a population; they in turn may be composed of cells. Cells are the smallest units (excluding the virus) of organized matter and energy which produce life. Certain units of the cell, when studied in isolation, apart from the organized cellular structure, hold the secret of life itself. The parts of a cell with these specialized functions, are called organelles.

The organism is, first, a highly ordered system of large energy-producing molecules and cells, but the maintenance of life is also dependent on the organism's contribution, and the contribution of other living things to the population-community-ecosystem, and finally the biosphere.

THEME F-3: Structure and function are often interdependent.

On every organizational level of matter, scientists have used the interdependence of function and structure as a useful tool. In most cases, if the function of a unit of matter can be observed, the scientist can make informed guesses as to its structure, even without direct observation. Also analysis of structure can give the scientist ideas as to what the function of the unit of matter may be.

A classic example of the use of this concept is found in the work of William Harvey, the English biologist. By studying the portion of the circulatory system that he could observe, he determined that the flow of blood must be continuous. This enabled him to predict the existence of capillaries, which were structures too small for him to see. In this way he used his observations of function to infer structure.

Another example of interdependence of structure and function is found in evolution. Investigation of cause--and--effect--evolutionary theories were at first misinterpreted by Lamark, when he predicted that function gave rise to structural adaptations. Experimental research indicates that structures evolved which made some organisms more adaptable to their environment than others. Organisms which evolved parts that did not successfully function within their environment did not survive.

Yet another example is found in genetics. Geneticists observed that inheritance seemed to follow certain patterns, and searched for the kind of physical structures which might hold the key to inheritance. They first realized the significance of the chromosomes, then genes, and eventually even the molecular structure, by searching for functional relationships.

Care must be taken however, when gauging the interdependence of parts and their function. Invalid conclusions of considerable significance have been drawn from inferences made about structure and function. An example of this can be found in the work of the scientists who set up a planetary model for the atom (the Bohr atom). This structural model gained wide acceptance, because its structure seemed to fit with the function of an atom according to the observations of the time. The different structural model of the atom that resulted from further observations and calculations does not discredit the use of interdependency as a research tool, but only serves to warn us against the drawing of hasty conclusions from incomplete observations.

In general, scientists form theories, rather than conclusions, on the basis of interdependence of structure and function and revise their theories to encompass new evidence when it is obtained. This use of the concept has made it one of the most important tools in the work of the scientist.

THEME G: Units of matter interact.

The properties and behavior of every unit of matter in the universe are dependent upon its interactions with other units of matter. In analyzing the behavior of a particular unit of matter, some interactions are selected which seem to be more significant. In this way different types of interactions are investigated and the changes in form, properties, or position which they produce are analyzed. At all levels of organization, interactions of matter are the sole evidence for not only the relationships between units but even the basic properties of individual units. Thus, the study of interaction constitutes a large part of scientific investigation, and such studies have led to a number of closely related concepts.

THEME G-1: The bases of all interactions are electrical, magnetic, gravitational, and nuclear forces whose fields extend beyond the vicinity of their origin.

In every interaction it is found that a force comes into play. These forces seem at first to be of many types, but three types stand out as being the bases of a great many interactions. These are the electrical, the magnetic, and the gravitational forces. Each has the rather amazing property of acting at a distance; that is, they permit interactions to take place without any direct contact between the units of interacting matter.

There are a great many other interactions which seem to be of an entirely different type, since they require at least a surface contact between the bodies. A closer look at such interactions on a microscopic level, however, leads to a quite different conclusion. It is now believed that all contact interactions are basically due to the electrical forces which bind electrons to nuclei to form atoms, and atoms to atoms to form molecules. What appears to be a direct contact between the surfaces of two interacting bodies is actually only a relatively close proximity between molecules, calling into play the attractive and repulsive action of electrical forces.

How does this accout for such interactions as the bouncing of a ball on the floor? As the ball strikes the floor, molecules of the ball are forced out of their normal position in the rubber structure by the electrical forces of the floor's molecules. The floor, too, is somewhat deformed by the collision so that now the forces between molecules for both the ball and the floor are no longer in equilibrium. As the unbalanced forces restore the ball and the floor to their original shapes, the ball is forced away from the floor until the distance between unlike molecules becomes too great for further significant influence. It appears that the contact is broken but actually at no point in this process did the molecules of the floor and the ball "contact" one another in the usual sense of that word. On a microscopic level the surface of the floor is not a well-defined plane which allows no penetration by the ball but instead is a deformable array of molecules which are at least slightly displaced by electrical forces when the molecules of the ball come close to them.

Many other examples can be given in which electrical forces between atoms or molecules are found to be the basis for what appear to be contact interactions. When a piece of paper is torn apart, the electrical bonds between like molecules are disrupted. The viscous forces which resist rapid motion through a fluid can be traced to electrical forces between the molecules of the fluid. A chemical reaction changes the electrical bonds between atoms making up a molecule and rearranges the atoms by different electrical bonding into a new molecule. Sound is the movement through the air of a compressional disturbance, and again it is the electrical force between molecules of the air which causes them to resist the compression and thus pass along the disturbance to nearby molecules. Light is now known to be a combination of an electrical field and a magnetic field which moves through space and interacts with certain devices (the eye, the photographic film, the photoelectric cell) which respond to fluctuating electric or magnetic fields. Such a combination is commonly referred to as an electromagnetic field.

Thus, by looking at interactions on the atomic level it can be seen that even the so-called contact interactions are based on action-at-a-distance forces which are closely related to the electrical and magnetic forces which can be observed on a larger scale with charged bodies and magnets. On the atomic level the forces are not electrostatic; that is, they have properties which depend upon the dynamic nature of the atom or molecule, but they are still basically due to the fact that the interacting particles possess an electrical charge. Magnetic forces due to the motions of electrical charges are also present and sometimes play an important role, but the electrical forces have been emphasized above, because they dominate in most atomic interactions. Gravitational attractions between individual atoms or molecules are also assumed to be present, but they are negligibly weak in comparison with the other forces. Only for large bodies do the gravitational forces become observable.

When it was discovered that the nucleus is made up of particles (protons and neutrons) which have electrical and magnetic properties, it was thought that perhaps the nucleus was held together by electrical and magnetic forces. It was soon found, however, that this could not possibly be the case, for not only are those forces far too weak to produce the observed binding but also the electrical forces push the protons apart rather than bind them together. Gravitational forces are much too weak to have any effect whatsoever on the binding of protons and neutrons together in the nucleus. Thus, it must be postulated that there is at least one other type of force, the nuclear force. It is now believed that there are actually two kinds of nuclear force, one considerably weaker than the other.

Nuclear forces also act without direct contact between the interacting particles, but unlike the other forces (electrical, magnetic, and gravitational) the strength of the nuclear forces does not vary inversely with the square of the distance between particles. The nuclear forces are much stronger than the other forces but they are effective over distrances which are very short (roughtly equal to the diameter of a nuclear particle). Studies of radioactivity, high energy collisions, and interactions of elementary particles have led to considerable progress in understanding the two nuclear forces. They are not yet fully understood, however, and they do not play a significant role in most of the interactions which we observe on the macroscopic scale.

In summary, then, it is our present belief that all interactions have as their bases only four forces. The electrical-magnetic force, the gravitational force, the strong nuclear force, and the weak nuclear force. The electric and magnetic forces are grouped together because they are intricately related, and cannot even be uniquely distinguished by different observers moving with respect to one another. This is not to say that these forces always manifest themselves in the same way. The bonding of atoms together to form molecules is a complex interaction, which requires quantum mechanics to describe the nature of the forces and give understanding to the bonding properties. To say that the basis of such an interaction is an electrical force may be an over-simplification, but it is still an important concept that all forces can be classified basically in the four categories discussed above and that, as yet, no additional basic types of forces have been discovered.

THEME G-2: Interdependence and interaction with the environment are universal relationships.

Interaction and interdependence are found in the smallest subatomic particles and in the most gigantic astronomical bodies. Nothing in the universe exists in isolation, for every object which exists is either dependent upon an interacting event for its origin, or is in the process of change due to interactions.

Units of matter interact when forces are applied to them: Basic forces are electromagnetic, gravitational or nuclear. Energy may pass from one body to another by direct contact or by radiation. Interactions within an atom hold its various parts together and establish the energy levels of the electron configurations. Interactions between the orbital electrons of one atom with those of another establish the bondings of molecules. These molecules in turn are held together in interacting systems, such as in crystals, or varieties of gaseous, liquid or solid matter.

Living things and the parts of living things react with their environments. The environment consists of both living and non-living things and may be external, surrounding the organism, or internal, found within the organism. These interactions result in a balanced equilibrium, whose limits determine the continued existence of the organism or its parts. The components of a living cell are integrated by interactions, and the cell as a whole dynamically interacts with its environment by exchanging matter and energy across the cell surface. At the higher organizational levels of organism, population, community, and ecosystem, the components within any given unit interact with each other, and the unit as a whole exchanges matter and energy with its environment.

All bodies in the universe are influenced by all other bodies. Many of the actions observed on the surface of the earth are the direct or indirect result of the effect of the sun and the moon. The weather and tides result from solar and lunar interactions with the earth.

Many interdependent events which occur in the natural order are cyclic in character. A pattern of sequential events exists which gives rise to a repetitive chain of events. These cyclic phenomena are therefore a series of predictable events in which one link of the chain is dependent upon its preceding link. Food cycles, water cycles, and life cycles are a few examples of dependent cyclic interactions.

A food chain links members of an ecosystem together. Green plants begin the chain (phytoplanktons in the marine ecosystem). The green plants, using light from the sun for energy, and water, and carbon dioxide, manufacture food. A consumer comes along and eats the plant. A second-order consumer eats the first. We can even have a transfer of food and energy from the producer to a third-order consumer or even to a higher level.

Another order of interactions are evolutionary events which produce predictable changes in certain kinds of objects over long periods of time. One theory claims that even atoms, interacting with one another, evolved over eons of time, give rise to the present assemblage of different kinds of elements. Another evolutionary thesis describes the progress of stars all the way from young gaseous nebulae to pulsating dying stars. Still another interacting series of events has produced the evolution of rocks from igneous to sedimentary and metamorphic.

Perhaps the best known evolutionary product of interactions are changes which occur in living organisms over long periods of time. From the origin of the first living particle, the evolution of living organisms was probably directed by environmental conditions and the changes occurring in them. A soup of amino acid-like molecules, formed in pools some 3 billion years ago, interacted with oxygen and other elemental constituents of the earth, probably giving rise to the first organization of matter which possessed the properties of life.

Evidence indicates that nearly 2 million living species, and millions of extinct species, are descendants of this early form of life. This diversity among living organisms is the result of natural selection, preserving characteristics which have allowed adaptation to the many kinds of environments on this planet. Long-term adaptation is evolution. Evolution results from mutations and genetic recombinations in the organism which, through natural selection, have produced a more efficient relation with the changing environment than less successful ancestors.

THEME G-3: Interaction and reorganization of units of matter are always associated with changes in energy.

The total relationships among all things and their environment can be compared to a spider's web, consisting of many interwoven threads which form a very complicated pattern. An interplay of matter and energy holds it together. There is, however, an orderly pattern to the total process.

Interactions of matter and energy are consistent and describable in terms of natural laws. The study of thermodynamics considers the laws of energy change and makes possible the prediction of many physical, chemical and biological events. The following two concepts are concerned with the changes in energy which accompany changes in the organization or state of matter.

1. In a closed system, when units of matter interact, the system tends toward a condition of equilibrium in which free energy is at a minimum. Free energy is the energy available for doing useful work.

2. In an open system, units of matter may interact in such a way as to maintain a steady state or condition of homeostasis.

Both of these concepts are concerned with the changes in energy which accompany changes in the organization or state of matter.

The First Law of Thermodynamics is a statement of conservation of energy: The energy associated with changes in the state of matter may change in form, but the total amount of energy in the system and its environment remains constant (Theme D). However, potential energy (positional, electrical, light, chemical, atomic) may be easily and completely converted to heat, but the conversion is not completely reversible. For instance, the heat obtained from an electric heater can be reconverted to electricity, but not all of it. Degradation of all forms of energy to irretrievable thermal energy (molecular disorder) is common in our every day experience. The universality of this loss of available energy through degradation to thermal energy leads to the statement of the Second Law of Thermodynamics: Changes in the state of matter in closed systems spontaneously tend toward states of greater disorganization accompanied by a corresponding loss in free energy. As free energy is lost, the organization of the system is usually decreased; thus the amount of free energy and the amount of organization in the system are directly related. It is common experience that it takes free energy to build a house and keep it in repair.

If left to itself the house will eventually disintegrate; that is, the materials of the house will lose their organization and become scattered randomly over the ground. Outside free energy would have to be applied to restore the materials to their original state of organization. Water changing from liquid state to solid (ice) is an example of free energy loss.

Two significant implications of the Second Law of Thermodynamics follow:

1. The driving force of any chemical of physical change within a closed system may be defined as the difference in energy levels between two parts of the system. (Heat drives ice to water.)

2. All of the natural processes within the universe (considered as a single closed system) are tending toward maximum disorganization and minimum free energy. Free energy,(heat) is absorbed into the water as it changes from a low energy state (solid) to a higher level (liquid).

The concept of equilibrium refers to the condition of a closed system which has achieved the lowest possible free energy and the greatest possible disorganization. Closed systems not at equilibrium always tend toward the equilibrium state. If liquid water and its vapor are enclosed in a vessel (energy constant), the number of molecues of the liquid escaping into the vapor state will equal the number of molecules returning to the liquid from the vapor state at equilibrium. In this state of dynamic equilibrium there is a continual movement of molecules in both directions, but the rates of the opposing reaction (evaporation and condensation) are equal. Similarly, when a chemical reaction reaches equilibrium the average number of molecules changing from one form to another is the same as the number changing back to the original reacting chemicals.

If a system in equilibrium is opened and matter and/or energy is added or removed, the equilibrium point can be shifted in such a way that the reaction may go completely in one direction or the other. "Household ammonia" (NH_4OH) is formed when ammonia gas (NH_3) reacts with water (H_2O) and all three substances are in equilibrium as long as the container is closed. ($NH_4OH \rightleftharpoons NH_3 + H_2O$). If it is opened, the ammonia escapes and the reaction can proceed to completion ($NH_4OH \longrightarrow NH_3\uparrow + H_2O$).

It is essential to living organisms that their biochemical reactions are kept open and do not attain equilibrium, or all the living processes would soon cease. Biochemical reactions usually occur in a series of orderly steps, proceeding in one direction, and not reaching equilibrium, because the products of each reaction in the sequence are removed by becoming the reacting materials for the succeeding reaction. The maintenance of such an organized system requires a constant supply of free energy to the living organism. This constant flow of matter and/or energy in and out of a system is called steady state or homeostasis. This constant or steady exchange is not equilibrium because there is continual gain (as food for the organism) and loss (the giving off of heat and wastes by the organism).

The constancy of energy-matter relationships is fundamental to the existence of order in nature. Equilibrium and steady state are conditions dependent upon regulated predictable flow of energy and the changes produced by energy within a given system.

Since the whole universe is moving toward maximum disorder (minimum free energy), and since outside free energy must be utilized to create and maintain the order of a system (such as a living system), it follows that creating order in one part of the universe necessarily involves creating greater disorder in some other part. Future decisions about pollution control, use of atomic energy, overpopulation, must be made in the future on the basis of where can disorder be tolerated in order to bring about order where it is needed for survival.

Fundamental concepts of thermodynamics may be found in the study of a balanced aquarium unit in the lower grade levels, as well as in the study of molecular equilibrium in the senior high school.